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ESTABLISHMENT AND MANAGEMENT PRACTICES OF TWO NEW WARM-SEASON TURFGRASSES IN THE SOUTHERN TRANSITION ZONE

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ESTABLISHMENT AND MANAGEMENT PRACTICES OF TWO NEW WARM-SEASON TURFGRASSES IN THE SOUTHERN TRANSITION ZONE

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ABSTRACT

Seashore paspalum (*Paspalum vaginatum* O. Swartz) is a turfgrass that has become increasingly popular in southern coastal regions of the US because of its ability to tolerate salt stress. Another reason that this turfgrass is increasing in popularity is its aesthetically appealing striping ability. Seashore paspalum could also be beneficial in areas where potable water cannot be used for irrigation. Information on this turfgrass is limited in literature, particularly on the topics of establishment, scalping, and growing this turfgrass on inland sites in the transition zone.

A field experiment was conducted in Clemson, SC from May 2007 and 2008 to investigate sprigging rates, nitrogen rates, nitrogen sources, and mowing height on turfgrass quality, turfgrass coverage, clipping yield, root mass, and ball rolling distances. Treatments included ‘SeaDwarf’ seashore paspalum sprigged either at 91 or 182 m^3 ha^{-1} on May 17, 2007 and May 12, 2008, and urea, ammonium nitrate, or ammonium sulfate applied at 22 or 44 kg N ha^{-1} week. The initial mowing height was 32 mm in late July and gradually lowered to 25 mm in early August with a daily mowing frequency. Weekly measurements included percent coverage and visual quality and color ratings. Samples to determine root mass were collected eight weeks after sprigging. The high sprig rate reached 100% coverage and acceptable turf quality within five weeks in comparison with the lower rate which did not occur until seven weeks. High rates of fertility associated with high rates of sprigs produced the best quality and color ratings (greater than seven

consistently for both ratings). Ball roll distances greater than 3.1 meters were found with the lower mowing height (2.5 mm) by using a standard stimpmeter.

Another two-year field study was conducted in Clemson, SC in 2008 and 2009 to observe the effects of treatments of trinexapac-ethyl growth regulator at 0 or 0.03 kg ai ha^{-1} and nitrogen as urea at two rates of 22 kg ha^{-1} and 44 kg ha^{-1} applied weekly on turf quality, clipping yield, root mass, and ball rolling distances after a heavy scalping event. After scalping occurred at the lower mowing heights (2.3 mm), mowing heights were raised to 3.2 mm and 2.5 mm to observe the effect of mowing height on recovery. Raising N rates and a lower mowing height were the most significant curative factors to help the scalped seashore paspalum recover.

A third two-year field study was also conducted in 2008 and 2009 where preventative practice treatments were used to observe scalping occurrence and severity measuring turf quality, clipping yield, root mass, and ball rolling distance. The study treatments included aerification frequencies of once or three times per growing season, paired with either grooming once weekly or no grooming and two mowing heights of 2.5 or 2.3 mm. A mowing height of 2.5 mm and one aerification per growing season benefit turf quality for prevention of scalping occurrence and severity. Lower mowing heights (<2.3 mm) may be able to be maintained for a short period of time (one to two weeks) without falling below minimally accepted TQ, but prolonged periods of low mowing heights cause less desirable putting green turf due to scalping.

A fourth two-year study was conducted to determine factors affecting establishment time for 'Diamond' zoysiagrass (*Zoysia matrella* (L.) Merr.) as a putting green in the southern transition zone of the United States. Zoysiagrasses are not traditionally used as putting greens, but, the desire to maintain greens in shady areas has led to the development of zoysiagrasses that can tolerate lower mowing heights. Literature is limited on zoysiagrasses used as putting greens, rates of establishment, and management practices to hasten establishment. Two sprigging rates, three N sources, two N rates, and two mowing heights (2.5 and 3.2 mm) were compared at Clemson University, Clemson, SC. Sprigs of 'Diamond' zoysiagrass were planted at rates of 91 or 182 m^3 ha^{-1} in 2007 and repeated in 2008. Urea, ammonium nitrate, and ammonium sulfate were applied at 1.7 or 3.4 g N m^{-2} wk^{-1} from WAS (weeks after sprigging) 3 to 10. Turf color and cover results indicate high rates of fertility associated with high rates of sprigs produced 100% turf cover at WAS 11in 2007 and 13 in 2008. At the 2.5 mm mowing height, ball rolling reached to 2.6 m in August and was significantly faster than the 3.2 mm mowing height. Results show 'Diamond' zoysiagrass can be established within the same growing season to meet a playable putting green quality but the establishment speed may vary depending on summer monthly temperature fluctuations.

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CHAPTER I. LITERATURE REVIEW

Seashore Paspalum

Seashore paspalum (*Paspalum vaginatum* O. Swartz) is a perennial C_4 turfgrass originating in South America, and is known by many other names such as silt grass and saltwater couch (Duncan and Carrow, 2000). It is a perennial warm-season turfgrass found in the Americas in coastal regions (Duncan and Carrow, 2000; McCarty, 2005; Turgeon, 2008). It is adapted to saline soils and also exhibits superior drought resistance, wear tolerance, submersion tolerance, salt tolerance, and recuperative potential (Beard, 2005). It is the first new development in warm-season turfgrasses in 30 years as a putting green turfgrass. Being a relatively new turfgrass, it has limited resources of literature and research, particularly on the management in inland areas in the southeastern states. Some of the seashore paspalum cultivars are dwarf types and have become popular in the last few years on putting greens in tropical and subtropical areas (Duncan and Carrow, 2000; McCarty, 2005; Patton and Trappe, 2008). Bermudagrasses (*Cynodon dactylon* (L.) Pers.) have been used for putting greens on courses in warmer climates where it is difficult to produce quality bentgrass (*Agrostis stoloniferous* L.) greens during the summer months, and is beginning to become more widespread, particularly in areas where poor quality irrigation water is used (Raymer et al., 2007). Its popularity on golf courses, sports fields, and lawns resulted from the appearance and environmentally friendly aspects of its management (Duncan and Carrow, 2002; Duncan and Carrow, 2000; Duncan, 1998).

Drought is becoming an increasing problem in the southeast and water usage for turf areas is becoming limited (NOAA, 2009). One potential management technique to reduce using potable water for irrigation is to use alternative, lower quality water sources that are not compatible with many current turfgrasses. Seashore paspalum can potentially utilize gray and saline water that is not suitable for consumer use with fewer problems than other turf species (Duncan, 2000; Duncan and Carrow, 2000; Lee et al., 2003; Lee et al., 2005; Unruh et al., 2007). One potential problem with seashore paspalum, though, is the tendency to scalp at the lower mowing heights often demanded by golfers desiring further ball roll. Other stresses that seashore paspalum can tolerate are low and high pH (from 4.0 to 9.8) and water logging conditions often associated with coastal areas (Duncan, 1998; Duncan and Carrow, 2000).

Some of its traits include fine leaf texture, low fertilizer inputs, low mowing heights, and the ability to maintain green color longer in the fall than bermudagrass (Duncan, 1998). Although paspalum is often compared to bermudagrasses, the management practices have their own unique strategy. Seashore paspalum is mostly established by sprig or sod since its seeds are not viable in most cases due to self incompatibility (McCarty, 2005; Duncan and Carrow, 2000).

Establishment of seashore paspalum is one of the most important parts of the growing process. Seashore paspalum establishment with salt levels of 5,000 to 10,000 ppm are a challenge with higher levels nearly impossible (McCarty, 2005; Duncan and Carrow, 2002). Recommended rates of fertilization are 98 to 147 kg ha^{-1} of phosphorus and potassium for root establishment and rhizome and stolon growth, and spoon feeding nitrogen with 24 to 49 kg ha^{-1}on a two to six week schedule. The nitrogen fertilization schedule depends on the rate at which is expected to establish. Lowering mowing heights below 12.7 mm will promote faster growth, spreading, and better shoot density (Duncan, 1998; Duncan and Carrow, 2000).

High nitrogen rates during the transition from grow in fertility to mature turf maintenance leads to severe scalping (Duncan and Carrow, 2002a; Duncan and Carrow, 2000). Nitrogen fertility should be lowered quickly after grow in to reduce thatch and scalping potential. The stiff upright growth habit and succulent leaves of seashore paspalum creates a much closer mow because the canopy doesn't slow the mower as much. The lean fertilizer programs needed for successful seashore paspalum turf can be indicated by the development of dollar spot (*Sclerotinia homeocarpa* F.T. Bennett). Nitrogen from soluble sources are applied from sources that fit the management budget, and at low rates because seashore paspalum responds so rapidly (Duncan and Carrow, 2002b).

Some disadvantages and contradicting findings about seashore paspalum include poor shade tolerance, cold tolerance, thatch production, sensitivity to herbicides, sensitivity to dollar spot, brown patch (*Rhizoctonia* spp.), and nematodes (Cardona et al., 1997; Trenholm et al., 1999, 2000, 2001; Duncan and Carrow 2000; Cyril et al., 2002; Jiang et al., 2004; Lee et al., 2004, 2005, 2007; Unruh et al., 2006, 2007). As a potential new putting green turfgrass in the transition zone, information on seashore paspalum nitrogen use, pest potential and mowing heights associated with playability is limited.

Sprigging and Establishment

Sprigging is a method of uniform vegetative establishment by scattering stolons, rhizomes, and/or tillers across the planting area followed by pressing them into the soil, topdressing, and rolling (Beard, 2005; McCarty, 2005). It has a more rapid rate of establishment than seeding, and is far less costly than sodding (McCarty, 2005). Another great benefit to sprigging over sodding is the lack of soil imported into the new planting area that can contain diseases, insects, and affect water movement in incompatible soil types (McCarty, 2005). Sprigging usually begins with the preparation of the planting area similar to other turfgrasses. To improve results the area should be weed free, moist, and tilled to provide good soil to node contact. Rates for sprigging can range from 17 to 57 m^3ha^{-1}, with a higher sprig rate providing complete coverage more quickly, depending on fertility, irrigation scheduling, and water quality (Duncan and Carrow, 1999; McCarty, 2005). Since there is often confusion about the definition, these sources are using a bushel as defined at 1.24 ft^3, 1 $yard^2$, or 0.035 m^3 (McCarty, 2005). Pressing the sprigs into the soil and topdressing increase the soil contact for better survivability, prevent drying out, and decrease light to the nodes (McCarty, 2005; Duncan and Carrow, 1999). Sprigs should always be watered immediately and frequently thereafter to prevent drying for two to four weeks (McCarty, 2005). “Grow-in” is referred to as the period of time immediately following seeding or vegetative propagation, and is considered the most overlooked expense of construction (Beard, 2005; McCarty, 2005). Irrigation, fertility, and mowing are especially important for this time frame. The time frame for paspalum grow-in is usually between two and three months, which heavily depend on nitrogen availability, water quality and quantity, as well as the quantity and quality of sprigs planted (Duncan and Carrow, 1999). Paspalum has little nitrogen uptake during the initial month of establishment, where 16 to 24 kg N ha^{-1} biweekly will be adequate, using a ratio of 1:2:3 or 1:3:4 N:P:K to promote root development (Duncan and Carrow, 1999). At about 5 to 6 weeks of grow-in, N applications should increase to 24 to 48 kg N ha^{-1} using a highly soluble N source and repeating on 7 to 14 day cycles. Nitrogen should be reduced when transitioning into a mature turf program (Duncan and Carrow, 1999). During this time it is especially important to transition the turf, once established, from light and frequent irrigation to prevent drying out, to deeper and infrequent applications to promote root elongation (Duncan and Carrow, 1999; McCarty, 2005). Grow-in time is reduced significantly when the turfgrass is lightly verticut on a regular schedule starting five to six weeks after sprigging (Duncan and Carrow, 1999). Mowing heights between 13 and 20 mm helps to achieve a dense canopy with short internodes (Duncan and Carrow, 1999).

Nitrogen

Seashore paspalum has good color at low nitrogen rates, indicating a low N rate is practical for this species (Duncan and Carrow, 2002a). When fully established, paspalum uses 40 to 50% of the total annual N required for a hybrid bermudagrass (Duncan and Carrow, 1999; Beard et al., 1982, 1991).One study suggests seashore paspalum utilizes a fertilization program close to a cool-season grass, requiring only 244 kg N ha^{-1} per year, applied as light summer applications and moderate in the spring and fall (Duncan, 1998b). An indicator of proper fertilization on seashore paspalum is the appearance of dollar spot (Duncan and Carrow, 2002a). Applications of 16 to 24 kg N ha^{-1} per application per month during the growing season for non-overseeded turf is recommended (Duncan, 1998b). Most warm-season grasses use N in both NO_3^- and NH_4^+ forms, but paspalum requires that the N in NH_4^+ to be transformed by the nitrification process to NO_3^- (Duncan and Carrow, 1999). The bacteria responsible for this transformation are Nitrosomonas and Nitrobacter and require soil temperatures to be >12.8° C, and pH > 5.5 (Duncan and Carrow, 1999; McCarty, 2005; Brady and Weil, 2001). There are several speculations on why paspalum is more efficient with NO_3^--N, mostly relating to the harsh, saline environments where they evolved from (Duncan and Carrow, 1999). The deep rooting ability and high N uptake efficiency make using low annual N coupled with spoon feeding useful and beneficial (Duncan and Carrow, 1999). Higher N rates will continue to be taken up by the plant, but lead to reduced drought tolerance, succulent tissue, higher growth rates, and increased susceptibility to scalping (Duncan and Carrow, 1999; Beard et al., 1982, 1991; Gibeault et al., 1988; Harivandi and Gibeault, 1983). Management practices to reduce puffiness from thatch buildup can help to alleviate problems, but an easier and healthier method to reduce thatch buildup would be to follow a lower rate fertility program to decrease growth (Duncan and Carrow, 1999).

Growth Regulator

Plant growth regulators (PGRs) are chemicals that alter the growth processes. PGRs that occur naturally in plants include abscisins, auxins, cytokinins, and gibberellins (Beard, 2005). Turf managers often use exogenously applied PGRs on high quality athletic turf to suppress vegetative growth and seed head production (Ferrell et al., 2003). A reduction in growth also means that mowing frequency can be reduced (Ferrell et al., 2003); as well as a reduction in the chances for scalping since scalping occurs when too much green tissue is removed during any one mowing (Beard, 2005; McCarty, 2005). Information on growth regulators for seashore paspalum is limited, but it has been suggested trinexapac-ethyl (TE) applications should be at rates no higher than half the labeled rate for bermudagrass and followed by a nitrogen application to reduce bronzing (Duncan and Carrow, 1999). When trinexapac-ethyl was compared to paclobutrazol, another growth regulator, on seashore paspalum, the seashore paspalum exhibited symptoms of injury at the lowest rates of TE, while paclobutrazol did not injure seashore paspalum at the highest rates used (Ferrell et al., 2003).

Scalping

Scalping occurs when excessive amounts of green tissue are removed at any one mowing and exposed stems, stolons, and dead leaves create a stubbly, brown appearance (Beard, 2005; McCarty, 2005). Susceptibility of turfgrasses to scalping, as well as recovery ability, differs between species and cultivars (Duncan and Carrow, 2002a). Seashore paspalum's tolerance to scalping is not as good compared to bermudagrass and zoysiagrass (Duncan and Carrow, 2002b). Mowing height influences the occurrence of scalping and wear, but fertility, topdressing, thatch management, irrigation, and mower type, when managed correctly, enable lower mowing heights without having scalping problems (Trenholm et.al, 1999, 2000, 2001; McCarty, 2005; Duncan and Carrow, 2002a). When seashore paspalum is scalped, the plant maintains and establishes roots and rhizomes, while shoot growth is not as active at the time. This is unlike bermudagrass where shoot growth is very vigorous for the plant (Duncan and Carrow, 2002a). Excess nitrogen fertility can have a major effect on scalping on grasses including seashore paspalum as it causes excessive shoot growth (Duncan and Carrow, 2002a). The fertilization program should follow similarly to a cool season program, light in the summer and moderate spring and fall fertilization (Duncan, 1998b; Duncan and Carrow, 2002a). Thatch buildup and puffiness, leading causes of scalping, can also be minimized with a proper fertility program (Duncan and Carrow, 2002a). In the event that scalping does occur from improper fertilization or mowing schedule, calcium nitrate [$Ca(NO_3)_2$] can be used to quickly heal affected areas (Duncan and Carrow, 1999). Selection of ecotypes that tolerate the target mowing height is also important when using seashore paspalum since there is a vast difference between ecotypes (Duncan and Carrow, 1999). Additionally, mowing heights greatly affect the occurrence of scalping. Lower mowing height also produced shortened internodes, denser canopy, darker green color, and higher turf quality on ecotypes used for golf greens mowed at 3-4 mm as compared to Tifgreen bermudagrass (*Cynodon dactylon* X *C. transvaalensis* Burtt Davy) mowed at the same height (Duncan, 1999). Lower mowing heights (<13 mm) have also been shown to allow for turfgrass to compete with weeds better and also had better fall color retention (Duncan and Carrow, 1999).

Aerification

Aerification, as defined by Beard (2005), is working the turf soil without harming the turf. It is one of the many types of soil cultivation that reduces soil compaction and thatch accumulation, ultimately improving drainage, gas exchange, deeper rooting, and water penetration (McCarty, 2005). Core aerification, where a hollow tine cuts into the soil surface, brings out a core of turf, and leaves a hole in the turf, is most beneficial to alleviating compaction and reducing thatch buildup (McCarty, 2005). Cores can be removed on closely mown turf due to the unattractive appearance, or on higher mown turf, broken up by dragging with a mat or brush. Aerification as frequent as every two to three weeks on highly trafficked situations such as sports fields is needed to alleviate the effects of scalping (Duncan and Carrow, 1999). Keeping moisture levels slightly below field capacity helps to ensure removal of full cores (Duncan and Carrow, 1999). Topdressing after core aeration helps to keep the holes open for movement of air, water, and chemicals, and to optimize root growth (McCarty, 2005; Duncan and Carrow, 1999).

Dollar Spot (*Sclerotinia homeocarpa* F.T. Bennett)

Dollar spot is a turf disease that occurs in closely mown turf as small, circular, sunken patches of blighted turf that rarely exceeds five cm in diameter (Smiley et al., 2005). In severe cases, the disease will coalesce into larger irregular shaped patches of small, yellow-green, chlorotic lesions with a reddish-brown border and extend across the full width of infected leaves, followed by leaves turning a tan to bleached-straw color (Beard, 2005; Smiley et al., 2005). *Sclerotinia homeocarpa* is present in most warm and cool-season grasses throughout the world and was first reported as a turfgrass pathogen in 1937 (Beard, 2005; Smiley et al., 2005). Activity is favored when temperatures are 15 to 25° C with dew formation (Beard, 2005). When the pathogen is active, a white fungal mycelium appears like cobwebs on the turf when dew is present (Beard, 2005; Smiley et al., 2005). The pathogen survives during less than favorable conditions as mycelium, and problems resurface when conditions are right. The pathogen can be transported by people, equipment, animals, water, and wind (Smiley et al., 2005). Control of the disease can be accomplished by use of fungicides such as Chlorothalonil, or by increasing nitrogen (Beard, 2005; Smiley et al., 2005). Although *Sclerotinia* has shown resistance to several common fungicides, alternating or tank mixing fungicides with different modes of action in a program can control the disease. With this pathogen, the best method for control is a sound program that will enhance growth and vigor in the turf stand (Smiley et al., 2005)

‘‘Diamond’’ Zoysiagrass

Zoysiagrasses are a popular warm-season, perennial turfgrasses used on golf courses, sports fields, home lawns, and commercial landscapes from the northern transition zone to the southern region in the United States (Beard, 2002; Engelke and Anderson, 2003). Most commonly used zoysiagrasses in these zones include three species of Zoysia: *Zoysia matrella* ([L.] Merr.), *Zoysia japonica* (Steud.), and *Zoysia pacifica* (Willd. ex Thiele) (Engelke and Anderson, 2003). Zoysiagrass has a wide range of leaf textures and appearances and provides excellent summer growth performance compared to cool-season turfgrasses in the transition zone. It forms a dense, uniform turf by producing both rhizomes and stolons. It tolerates stress and unfavorable conditions including lower light intensity (Qian and Engelke, 1999a; Baldwin et al., 2009), moderate to high salinity (Marcum et al., 1998; Qian et al., 2000), moderate drought conditions (Qian and Engelke, 1999b; White et al., 2001), and cold temperatures (Warmund et al., 1998; Patton and Reicher, 2007). High quality of turf appearance under a wide range of environmental conditions have increased zoysiagrass popularity. ‘Diamond’ zoysiagrass (*Zoysia matrella* (L.) Merr.) was developed and released by the Texas Agricultural Experiment Station in 1996 and registered in 2002 (Engelke et al., 2002). It has adapted throughout the southern region to the transition zone of the United States as a fine turf requiring a medium to high maintenance for use on golf course tees, fairways, sports fields, and home lawns (Engelke et al., 2002).

Sprigging and Establishment

Zoysiagrass establishment using vegetative plugs or sprigs can take months or even longer to reach adequate coverage and turf quality in comparison with other warm-season turfgrasses (McCarty and Miller, 2002). Furthermore, improper establishment of warm-season turfgrasses may increase plant stress to pest problems, winter hardiness, maintenance costs during establishment, and reduce overall turfgrass quality and function of the desired turf use (Richardson and Boyd, 2001). However, among zoysiagrasses, relatively faster establishment rates from plugs have been observed for cultivars *Z. japonica* than for *Z. matrella* (Patton et al., 2007a). In comparison with sod establishment, zoysiagrass sprig establishment has been shown to be economically feasible and practical. Planting time, fertilizer input, and sprigging rates affect warm-season turfgrass establishment speed and quality depending on location (Richardson and Boyd, 2001; Patton et al., 2004; Guertal, and Hicks, 2009). Increased N fertilization rate during establishment can hasten vegetative establishment. Richardson and Boyd (2001) reported a 5 to 10% increase in turf cover of 'Meyer' zoysiagrass (*Zoysia japonica* Steud.) 120 d after sprigging at a low rate of 18 m3 ha^{-1} when monthly N was increased from 0 to 2.5 g m^{-2}. There is a lack of published research regarding N rates, N sources, and sprigging rates for zoysiagrass putting green establishment. However, a few seeding rates studies about zoysiagrass establishment were reported. Portz et al. (1981) recommended seeding zoysiagrass at rates of 3.8 to 9.8 g m^{-2}, whereas Landry and Choi (1995) found 9.8 g m^{-2} produced the highest shoot and root growth in greenhouse studies. Carroll et al. (1996) reported that sprigs (using sprigging rates of 19 or 31 m3 ha^{-1}) of

‘Meyer’ zoysiagrass treated with urea-N, a biostimulator, and one of three preemergence herbicides or one of two postemergence herbicides hastened establishment in two field studies. A monthly rate of at 4.9 g N m^{-2} applied during the growing season had no influence on sprig establishment in the first year, but slightly increased (+5%) turf cover the second year with a higher sprigging rate of 31 $m^3 ha^{-1}$. Overall, sprigging rate recommendations for establishment are lacking or inclusive.

CHAPTER II. SEASHORE PASPALUM PUTTING GREEN ESTABLISHMENT AS AFFECTED BY SPRIGGING RATES, NITROGEN SOURCES, AND NITROGEN RATES IN THE SOUTHERN TRANSITION ZONE

Abstract

In order to meet water restrictions, turf managers in coastal areas are irrigating turfgrass with increasingly poor quality water and at lower volumes. Seashore paspalum (*Paspalum vaginatum* Swartz.) may offer a solution for many since it is known to tolerate poor quality water including irrigating with sea water. However, information on using Seashore paspalum as a putting green in inland areas is lacking. The objective of the study was to examine the establishment efficiency of a 'SeaDwarf' Seashore paspalum putting green with two sprigging rates, three nitrogen (N) sources, and two N rates in the inland transition zone. The study was conducted in a split block design with three replications at Clemson University in Clemson, South Carolina in 2007 and 2008. 'SeaDwarf' was sprigged either at 91 or 182 m^3 ha^{-1} on May 17, 2007 and May 12, 2008. Urea, ammonium nitrate, or ammonium sulfate was applied at 22 or 44 kg N ha^{-1} $week^{-1}$. These soluble N sources were dissolved in water to apply as a liquid for 10 weeks with a CO_2 backpack sprayer followed by a light irrigation (10 to 15 mm water) to reduce potential of foliar burns. Potassium and phosphorus were applied as 19-19-19 at 49 kg N ha^{-1} yr^{-1} prior to sprigging and additional applications of P and K as liquid forms at 24.5 kg P ha^{-1} $yr^{-1}$and 49 kg K ha^{-1} yr^{-1}, respectively in week 6 after sprigging. The initial mowing height was 32 mm in late July and gradually lowered to 25 mm in early August with a daily mowing frequency. Weekly measurements included percent coverage and

visual quality and color ratings. Samples to determine root mass were collected eight weeks after sprigging. The high sprig rate reached 100% coverage and acceptable turf quality within five weeks in comparison with the lower rate which did not occur until 7 weeks. High rates of fertility associated with high rates of sprigs produced the best quality and color ratings (greater than seven consistently for both ratings). Ball roll distances greater than 3.1 meters were found with the lower mowing height (25 mm) by using a standard stimpmeter.

Introduction

Seashore paspalum, although by many other names such as seashore paspalum, silt grass, and saltwater couch (Duncan and Carrow, 2000), is a perennial warm-season turfgrass that is native to tropical and sub-tropical areas (Turgeon, 2008), and is found in the Americas in coastal regions (Duncan and Carrow, 2000; McCarty, 2005; Turgeon, 2008). It is the first new development in warm-season turf grasses in 30 years as a putting green turfgrass. Seashore paspalum is a relatively new turfgrass often compared to bermudagrasses, and it has limited resources of literature and research that have been completed, particularly on the management in inland areas in the southeastern states. Some of the seashore paspalum cultivars are dwarf types and have become popular in the last few years on putting greens in tropical and subtropical areas (Duncan and Carrow, 2000; McCarty, 2005). Bermudagrasses have been used for putting greens on courses in warmer climates where it is difficult to produce quality bentgrass (*Agrostis stoloniferous* L.) greens during the summer months and seashore paspalum is beginning to become more widespread, particularly in areas where poor quality irrigation water is used

(Raymer et al., 2007). Its popularity on golf courses, sports fields, and lawns is increasing rapidly because of the appearance and environmentally friendly aspects of management (Duncan and Carrow, 2002; Duncan and Carrow, 2000; Duncan, 1998). It has drought tolerance similar to centipedegrass (*Eremochloa ophiuroides* (Monro.) Hack), and is highly tolerant of poor water quality including reclaimed water and ocean water for some varieties (Carrow and Duncan, 2002a; Duncan, 1998). Poor water quality isn't the only stress that seashore paspalum tolerates well, it can also tolerate pH from 4 to 9.8 and water logging conditions (Duncan, 1998; Duncan and Carrow, 2000). Some of its traits include fine leaf texture, low fertilizer inputs, low mowing heights, and the ability to hold green color longer than bermudagrass (Duncan, 1998). Although paspalum is often compared to bermudagrasses, the management practices have their own unique strategy. Seashore paspalum is mostly established by sprig or sod since its seeds are not viable in most cases due to self-incompatibility (McCarty, 2005; Duncan and Carrow, 2000).

Establishment of seashore paspalum is one of the most important parts of the growing process. Seashore paspalum establishment with salt levels of 5,000 to 10,000 ppm are a challenge with higher levels nearly impossible (McCarty, 2005; Duncan and Carrow, 2002). Recommended rates of fertilization are 98 to 147 kg ha^{-1} of phosphorus and potassium for root establishment and rhizome and stolon growth, and spoon feeding nitrogen with 24 to 49 kg/ha on a two to six week schedule. The nitrogen fertilization schedule depends on the rate at which is expected to establish. Lowering mowing heights below 12.7 mm will promote faster growth, spreading, and better shoot density (Duncan, 1998; Duncan and Carrow, 2000).

High nitrogen rates during the transition from grow in fertility to mature turf maintenance leads to severe scalping (Duncan and Carrow, 2002a; Duncan and Carrow, 2000). The stiff upright growth habit and succulent leaves of seashore paspalum creates a much closer mow because the canopy doesn't slow the mower as much. Nitrogen fertility should be lowered quickly after grow in to reduce thatch and scalping potential. The lean fertilizer programs needed for successful seashore paspalum turf can be indicated by the development of dollar spot disease. Nitrogen from soluble sources are applied from sources that fit the management budget, and at low rates because seashore paspalum responds so rapidly (Duncan and Carrow, 2002b). Mowing height can influence the occurrence of scalping and wear, but there are other factors when managed correctly, can help to lower mowing heights without having scalping problems (Trenholm et.al, 2000). Improper fertility, topdressing, thatch management, irrigation, and mower type are some of the leading causes of scalping (McCarty, 2005; Duncan and Carrow, 2002a). Other than the cultural practices that can influence scalping, selection of turfgrasses used can also make differences. Some grasses have better recovering ability and differ in the management practices used to prevent and recover from scalping (Duncan and Carrow, 2002a). However, Seashore paspalum is known for its intolerant performance for scalping. When seashore paspalum is scalped, it maintains and establishes roots and rhizomes, and shoot growth is not as prolific at the time. This is unlike bermudagrass where shoot growth is very vigorous for the plant, so management techniques will differ for seashore paspalum (Duncan and Carrow, 2002a).

Excess nitrogen fertility can have a major effect on scalping on grasses as it causes excessive shoot growth. Seashore paspalum has shown to have good color at low nitrogen rates and this may be an indication that a low N rate is practical for this species (Duncan and Carrow, 2002a). One study indicates seashore paspalum should use a fertilization program similar to a cool season grass, receiving no more than 244 kg N ha^{-1} per year, light summer applications and moderate in the spring and fall (Duncan, 1998b). An indicator of proper fertilization on seashore paspalum is the appearance of dollar spot disease (Duncan and Carrow, 2002a). To maintain light and proper N rates, applications of 16 to 24 kg N ha^{-1} per application per month are recommended (Duncan, 1998b).

Verticutting and topdressing are two important cultural practices for any turf to minimize scalping. Seashore paspalum greens especially should have them performed regularly. Topdressing helps provide a smoother surface and maintain a thin thatch mat (McCarty, 2005; Turgeon, 2008). Turf not receiveing ample amounts of topdressing, particularly during grow in, will develop a puffy, spongy thatch layer and is more vulnerable to scalping (Duncan and Carrow, 2002a). Frequent and light verticutting can improve surface firming and help topdressing be incorporated into the surface of the canopy, but if good quality topdressing materials are used on paspalum, verticutting need may not be reduced (McCarty, 2005; Duncan and Carrow, 2002a).

Irrigation management is another critical area for paspalum. This grass has been shown to grow rapidly and have a poor root system with frequent and light irrigation schedules (Duncan and Carrow, 2002a). It also will not retain its full drought resistance with a poor irrigation schedule (Duncan and Carrow, 2002a). Overwatering paspalum can also lead to increasing the odds for scalping because of a shallow root system and puffiness. Although paspalum can tolerate water logging conditions, the plants will be more succulent and show an increase in shoot growth which can cause scalping (Duncan and Carrow, 2002a). Applications that are infrequent and replenish the root zone, rather than wetting the upper few inches, will provide a turf that can take advantage of rainfall and irrigation more efficiently (Duncan and Carrow, 2002a; Duncan, 1998b).

Water conversation strategies in turfgrass management have been a new challenge in the world including the southeastern United States, where the normal annual precipitation is much higher than arid regions in the world with an average range of 100 to 150 mm (Duncan and Carrow, 2000). However, uneven chronicle distribution of precipitation and local drought conditions further promote the use of non-potable, alternative irrigation sources for turfgrasses. Alternative irrigation water sources for turfgrass management include recycled water, storm water, saline ground water, and seawater blends, which contain much higher salt levels than potable irrigation water sources. Using alternative turfgrasses can be another strategy to meet the overall goal of water conservation. Seashore paspalum is a warm-season perennial grass particularly well-adapted to salt-affected areas common in coastal regions (Dudeck and Peacock, 1985; Duncan and Carrow, 2000).

Some disadvantages or contradicting findings about seashore paspalum include poor shade tolerance, cold tolerance, thatch production, sensitivity to herbicides, sensitivity to dollar spot, brown patch and nematodes (Cardona et al., 1997; Trenholm et al., 1999; Duncan and Carrow 2000; Trenholm et al., 2000; Cyril et al., 2002; Jiang et al., 2004; Lee et al., 2004; Lee et al., 2005; Unruh et al., 2006; Lee et al., 2007; Unruh et al., 2007). As a potential new putting green turfgrass in the transition zone, information on seashore paspalum sprigging rates, nitrogen use, and mowing heights associated with playability is very limited. Therefore, the objective of this study was to test seashore paspalum establishment using sprigs on inland sites in the transition to reach a playable putting green surface within one growing season with different sprigging rates and nitrogen rates and sounces.

Materials and Methods

Establishment and Treatments

Two experiments (one in 2007 and in 2008) were conducted over a 12 week period in Clemson, SC on Clemson University's turfgrass research plots. The 'SeaDwarf' Seashore paspalum sprigs were grown in Rembert, SC by Modern Turf Inc. They were delivered and installed on May 17, 2007 and May 12, 2008. The greens areas used for the establishment were existing bentgrass plots (465 m^2) on USGA spec greens mix consisting of 85% sand and 15% peat moss that was renovated for warm-season turf. The bentgrass was sprayed with glyphosate approximately one month before planting, allowed to die, and was removed with a sod cutter. The remaining soil was tilled with a rotary tiller several times and then dragged and rolled to smooth for planting. Heavy topdressing (25 m^3 ha^{-1} of 85:15 sand to peat moss mix) was applied to further smooth out the area. The sprigs were planted at 91 and 182 $m^3 ha^{-1}$. The green was again heavily top-dressed with 25 m^3 ha^{-1} of 85:15 sand to peat moss mix, and rolled with a greens roller. Sprigs were irrigated at 10 to 12 mm the day they were installed. The area was irrigated by hand for 2 weeks to prevent the soil from drying out. Water applications were started at 10 AM and were done every 2 hours until 4 PM. After the first 2 weeks, overhead irrigation was applied and hand watering applied only in critical areas.

Mowing was initiated on June 4th at a height of 15.3 mm. After 1 week, the mowing height was decreased to 12.7 mm and the total area mowed twice a week at 12.7 mm until the height was lowered on July 22nd to 3.2 mm and mowed daily. The treatments included a combination of 3 N sources (ammonium nitrate, ammonium sulfate, or urea) along with a N rate of 22 or 44 kg ha^{-1} wk^{-1}. A split block design was used to allow two mowing heights of 3.2 mm or 2.5 mm starting on August 10th. Nitrogen was applied to the appropriate block weekly starting June 8, approximately 2 weeks after sprigging (WAS), at the rates of 22 or 44 kg ha^{-1}. Three nitrogen sources were used: ammonium nitrate, ammonium sulfate, or urea. These nitrogen sources were dissolved into a solution and applied in a 1,000 ml volume per plot with a CO_2 backpack sprayer. Nitrogen rates were halved after the 8th application on the week of July 22. Spray volumes were also reduced to 800 ml. Phosphorus and Potassium were applied at 24 kg/ha bimonthly starting June 6.

Data Collection

Turf color was visually rated on a one to nine scale, where one = lowest quality as brown turf and nine = highest quality as dark green turf, and a reading of 6 was minimally acceptable. Turf cover was determined as percentage of green turf tissue cover weekly using a line intersec grid. The grid was an 18.5 cm by 18.5 cm frame made from 2.5 cm diameter PVC pipe with strings evenly spaced to form 100 equal small squares (1.85 by 1.85 cm). During weekly data collection, the grid was randomly placed on each plot and grid squares with green turfgrass shoots or leaves were counted to determine percent cover from each reading. Stimpmeter readings were taken 12 WAS on each plot to measure ball roll distance. Ball roll distance was measured three times in one direction and three times in the opposite direction, and then averaged for each plot. A mini stimpmeter, one third standard length (Mini-Stimp™, Scientific Golfer, 1971 N. Nowak Ave. Thousand Oaks, CA 91360) was used to keep ball roll within each plot, so averages were converted using a multiplication factor of three to simulate a full size stimpmeter reading. Clippings were collected from a 7.7 m^2 area once at 10 weeks after sprigging from each plot using a walk behind greens mower (Greensmaster 800; The Toro Company, Bloomington, MN), then oven dried at 80^{o}C for 48 h before weighing. Profile samples were also collected once at 10 WAS using a standard green cup cutter with 10 cm diameter to a depth of 25 cm. Canopy, stolons, rhizomes, and thatch were removed by hand and roots washed using a strainer to be soil free. Roots samples were oven dried (80°C), weighed, ashed in a muffle furnace (550°C) for three hours, and reweighed. Root data are presented as ash-free weight, i.e. oven dry weight minus ash weight (Snyder and Cisar, 2000).

Experimental Design and Analysis

The study area used each year was divided in half with each half randomly receiving one of the two sprigging rates. Whole plots for the six nitrogen treatments (three sources by two rates) and whole plots for two mowing heights were stripped across each other in a split-block design with three replications (Federer and King, 2007). Data was analyzed using the general linear model procedure of the Statistical Analysis System (SAS, 2006). Treatment by year interaction was detected, so results for each year were evaluated and discussed separately. ANOVA was performed to evaluate main and interaction effects of the treatment factors using $\alpha = 0.05$. Since this research reports progress over time in turfgrass establishment, bi-weekly data are presented for all treatments in turf cover and quality. Means separation was performed using Fisher's Protected Test for least significant difference (LSD) test with $P < 0.05$.

Results/ Discussion

Turf Cover and Color

Coverage ratings were different in 2007 and 2008, so results were analyzed separately (Tables 1 to 5). Yearly interactions occurred most likely due to the temperature variations in 2007 and 2008 in the Clemson area, SC. Between 1 and 2 WAS, there were 13 d with maximum temperatures below 29.4 ^{o}C in 2008 while there were only 8 d in 2007. Also, August average maximum temperature in 2007 was 35.5 ^{o}C compared with

31.8 ^{o}C in 2008 (NOAA, 2009) although no degree day differences were found between the two years. Perhaps cooler days in the early summer 2008 slowed the establishment speed for ‘‘Diamond’’ zoysiagrass. In 2007 TQ ratings were higher for all treatments receiving the high sprigging rate (182 m^3ha^{-1}) until 7 WAS (Table 1), where for one week TQ was not different. At 8 WAS the high sprigging rate again produced higher TQ. N sources affected TQ for some readings, but there was insufficient evidence to indicate one source provided better TQ during establishment. Although N sources did not affect TQ, the high N treatment (44 kg N ha^{-1}) performed 5-20% better than the lower N rate (22 kg N ha^{-1}) seven out of eight readings in 2007, where the one reading (8 WAS) showed that high and low rates of N were not different. TQ results in 2008 showed the same trends as in 2007, but TQ was possibly affected by lower air temperatures recorded in the early growing season in 2008 (Table 1). All TQ readings in 2008 showed that the higher sprigging rate (182 m^3ha^{-1}) and the high N treatments benefit TQ. Nitrogen sources, again, did not provide sufficient evidence that they affected TQ throughout the establishment in 2008. The only weeks affected were 1 and 2 WAS in 2008 (Table 1). Guertal and Hicks (2009) and Stiglbauer, et al. (2009) also reported similar findings on hybrid bermudagrasses, where N sources only had slight effects on establishment. N rate effects also showed similar results to these two studies where shoot density and turf quality increased as N increased.

Coverage in 2007 was affected only by sprigging rate for most readings. There were only instances where high N benefitted turf coverage in weeks four and five of 2007 (Table 2). N sources also were not a factor in coverage similar to results shown by

Guertal and Hicks (2009). High rates of sprigging reached 90% coverage for all N sources and N rates by 2 WAS, and 100% by 7 WAS. All treatments with the lower sprig rates reached 80% coverage by 3 WAS, 90% by 6 WAS, and 100% at 8 WAS. As mentioned, coverage in 2008 may have been affected by cooler air temperatures just after sprigging, causing coverage to be slow at first, but again showed no benefits from use of different N sources or higher N rates as all treatments with higher sprigging rates reached 90% coverage by 3 WAS and 100% by 7 WAS. The lower rate of sprigging reached 80% for all treatments by 4 WAS, 90% by 6 WAS, and 100% by 8 WAS (Table 2).

Root Weight, Clipping Yield, and Ball Rolling

Differences were not evident in root weight from samples collected at 10 WAS in either year (Table 3). Spring green-up differences also did not show any significance from sprig rate, N rate, or N source (data not shown). Ashed root weight results suggest no residual effects on future seasons when establishing with different sprig rates and N rates. The large difference in root weight likely came from the relatively higher temperatures in early summer 2007.

Differences from both years suggest mowing height had the most impact on clipping yield (Table 4). Sprig rates also affected the yield, but differently for the two mowing heights. At the high mowing height, lower sprigging rates frequently produced more clippings, and at lower mowing heights, more clippings were produced by the higher sprig rate.

Ball rolling is a very important consideration when establishing turfgrasses for use as a putting green, especially when dealing with the expectations of a membership. Ball rolling distances have been shown by Koeritz and Stier (2009) to decrease with an increase in mowing height and N rate on multiple bentgrass cultivars. In both 2007 and 2008 results indicate the lower mowing height had an advantage allowing ball roll distances of 270 to 300 cm whereas the high mowing height only achieved between 245 and 270 cm (Table 5). Stiglbauer, et al. (2009) also showed increasing N and increasing mowing height had a negative effect on ball roll distances.

Conclusions

'SeaDwarf' seashore paspalum is a turf that can be grown in with minimal N inputs, but provides better turf quality during the grow-in process with higher N rates. Sprigging rates can also impact grow-in time, but by 8 weeks, the low sprigging rate had reached 100% cover. Lower sprigging rates and lower N inputs established acceptable turf within 8 weeks. Establishing 'SeaDwarf' seashore paspalum can be hastened, but the use of lower sprig rates and lower N rates can provide the same quality turf, maybe just one to two weeks longer grow-in time will be needed. Lowering inputs will also provide savings to a budget and benefit the environment.

Table 1. Turf color readings of 'SeaDwarf' seashore paspalum established at two sprigging rates, three N sources, and two N rates in 2007 and 2008 with readings from 1-8 WAS.

Week 2

		------------------------- Means ------------------------			
Sprig Rate		**182 m^3 ha^{-1}**		**91 m^3 ha^{-1}**	**LSD**
	2007	6.6a		3.6b	0.2
	2008	6.6a		3.4b	0.2
N Rate		**44 kg ha^{-1}**		**22 kg ha^{-1}**	
	2007	5.4a		4.8b	0.2
	2008	5.4a		4.6b	0.2
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	4.9b	5.2ab	5.3a	0.3
	2008	4.9b	5.2a	4.9b	0.2

Week 4

		------------------------- Means ------------------------			
Sprig Rate		**182 m^3 ha^{-1}**		**91 m^3 ha^{-1}**	**LSD**
	2007	6.1a		5.1b	0.4
	2008	7.2a		5.1b	0.3
N Rate		**44 kg ha^{-1}**		**22 kg ha^{-1}**	
	2007	6.0a		5.2b	0.4
	2008	6.7a		5.7b	0.3
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	5.5a	5.4a	5.8a	0.5
	2008	6.1a	6.4a	6.0a	0.4

Week 6

		------------------------- Means -------------------------			
Sprig Rate		**182 m^3 ha^{-1}**	**91 m^3 ha^{-1}**	**LSD**	
	2007	7.6a	6.7b		0.2
	2008	7.6a	6.6b		0.3
N Rate		**44 kg ha^{-1}**	**22 kg ha^{-1}**		
	2007	7.3a	6.9b		0.2
	2008	7.3a	6.8b		0.3
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	7.3a	6.9b	7.2ab	0.3
	2008	7.0a	7.1a	7.2a	0.4

Week 8

		------------------------- Means -------------------------			
Sprig Rate		**182 m^3 ha^{-1}**	**91 m^3 ha^{-1}**	**LSD**	
	2007	6.2a	6.0b		0.2
	2008	7.6a	6.9b		0.2
N Rate		**44 kg ha^{-1}**	**22 kg ha^{-1}**		
	2007	6.1a	6.1a		0.2
	2008	7.5a	7.1b		0.2
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	5.9b	6.0b	6.4a	0.2
	2008	7.3a	7.3a	7.2a	0.2

Table 2. Weekly percent cover of 'SeaDwarf' seashore paspalum established May 2007 and 2008 using sprigs at two sprigging rates, three N sources, and two N rates with readings starting 1 WAS.

Week 2

			--- Means ---		
Sprig Rate		**182 m^3 ha^{-1}**		**91 m^3 ha^{-1}**	**LSD**
	2007	93.8a		66.3b	4.3
	2008	87.4a		57.0b	2
N Rate		**44 kg ha^{-1}**		**22 kg ha^{-1}**	
	2007	79.2a		80.1a	4.3
	2008	72.3a		72.0a	2
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	79.6a	81.4a	79.2a	5.3
	2008	72.4a	72.3a	71.8a	2.5

Week 4

			--- Means ---		
Sprig Rate		**182 m^3 ha^{-1}**		**91 m^3 ha^{-1}**	**LSD**
	2007	97.9a		88.3b	1.4
	2008	98.2a		85.8b	1.1
N Rate		**44 kg ha^{-1}**		**22 kg ha^{-1}**	
	2007	93.9a		92.3b	1.4
	2008	92.4a		91.6a	1.1
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	92.6a	94.0a	92.8a	1.7
	2008	91.8b	93.1a	91.2b	1.3

Week 6

		------------------------- Means -------------------------			
Sprig Rate		**182 m^3 ha^{-1}**	**91 m^3 ha^{-1}**		**LSD**
	2007	99.8a	96.0b		0.8
	2008	99.7a	94.9b		0.5
N Rate		**44 kg ha^{-1}**	**22 kg ha^{-1}**		
	2007	98.2a	97.6a		0.8
	2008	97.7a	97.0b		0.5
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	97.7a	98.1a	98.0a	1.0
	2008	97.5a	97.0a	97.4a	0.6

Week 8

		------------------------- Means -------------------------			
Sprig Rate		**182 m^3 ha^{-1}**	**91 m^3 ha^{-1}**		**LSD**
	2007	100.0a	100.0a		0.0
	2008	100.0a	100.0a		0.0
N Rate		**44 kg ha^{-1}**	**22 kg ha^{-1}**		
	2007	100.0a	100.0a		0.0
	2008	100.0a	100.0a		0.0
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	100.0a	100.0a	100.0a	0.0
	2008	100.0a	100.0a	100.0a	0.0

Table 3. Root samples of established 'SeaDwarf' seashore paspalum were collected August 2007 and 2008 and burned in a muffle furnace (550 °C) for 3 hrs. The data are presented as ash-free weights.

		------------------------- Means -------------------------			
Sprig Rate		**182 m^3 ha^{-1}**	**91 m^3 ha^{-1}**		
	2007	106.9a	96.2a		21.2
	2008	29.0a	27.8a		9.2
N Rate		**44 kg ha^{-1}**	**22 kg ha^{-1}**		
	2007	89.8b	113.2a		21.2
	2008	30.7a	26.2a		9.2
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	98.8a	96.1a	109.7a	26
	2008	31.6a	27.1a	26.5a	11.3

Table 4. Oven-dried clipping yields of established 'SeaDwarf' seashore paspalum collected September 2007 and 2008 using a walk-behind mower at two mowing heights.

		---------------------------- Means ----------------------------			LSD
Mow Ht.	Year	**3.2 mm**	**2.5 mm**		
	2007	3.8a	3.3b		0.4
	2008	5.0b	9.0a		0.4
Sprig Rate		**182 m^3 ha^{-1}**	**91 m^3 ha^{-1}**		
	2007	3.8a	3.3b		0.4
	2008	6.9a	7.2a		0.4
N Rate		**44 kg ha^{-1}**	**22 kg ha^{-1}**		
	2007	3.9a	3.2b		0.4
	2008	6.6b	7.5a		0.4
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	3.3b	3.9a	3.5ab	0.5
	2008	6.4c	7.7a	6.9b	0.5

Table 5. Ball rolling distances of established 'SeaDwarf' seashore paspalum by using a modified stimpmeter.

		---------------------------Means ----------------------			
Mow Ht.	Year	**3.2 mm**	**2.5 mm**		**LSD**
	2007	50.0b	53.7a		1.5
	2008	56.2b	59.8a		1.7
Sprig Rate		**182 m^3 ha^{-1}**	**91 m^3 ha^{-1}**		
	2007	51.4a	51.1a		1.5
	2008	58.1a	56.7a		1.6
N Rate		**44 kg ha^{-1}**	**22 kg ha^{-1}**		
	2007	50.1b	52.4a		1.5
	2008	56.4b	58.4a		1.6
N Source		**Ammonium Nitrate**	**Ammonium Sulfate**	**Urea**	
	2007	51.3a	51.1a	51.4a	1.8
	2008	58.3a	56.7a	57.2a	1.9

CHAPTER III. EFFECTS OF NITROGEN, GROWTH REGULATOR, AND MOWING HEIGHT ON SEASHORE PASPALUM RECOVERY FROM SCALPING

Abstract

One of the damages caused by lower mowing heights for a putting green is scalping. Since scalped turf on any area of a golf course is undesirable, minimizing the time to recover from scalping damages is important. As a relative new putting green turfgrass, seashore paspalum's scalping recovery capabilities at lower mowing heights has not been thoroughly evaluated in the inland southeastern region. A field study was conducted in the summer of 2008 and repeated twice in summer 2009 (on the same site and a new site) to evaluate treatments to reduce longevity of scalping effects on golf greens comprised of a USGA specification mix with 85% sand 15% peat-moss (v:v). The research greens were established using sprigs in 2007 and 2008. The curative treatments of trinexapac ethyl (TE) growth regulator at 0 or 0.03 kg ai ha^{-1} and nitrogen as urea at two rates of 22 and 44 kg N ha^{-1} were applied weekly after a heavy scalping event. After scalping occurred at the lower mowing heights (2.25 mm), mowing heights were raised to 3.18 mm and 2.54 mm to observe the effect mowing height on recovery. Raising N rates and a lower mowing height were the most significant curative factors to help the scalped seashore paspalum recover.

Introduction

Seashore paspalum is a perennial C_4 turfgrass that is South American in origin. It is adapted to saline soils and also exhibits superior drought resistance, wear tolerance, submersion tolerance, salt tolerance, and recuperative potential (Beard, 2005). One potential problem with seashore paspalum, though, is the tendency to scalp at lower mowing heights that are often demanded by golfers wanting faster ball speeds.

Susceptibility of turfgrasses to scalping, as well as recovery ability, differs between species and cultivars (Duncan and Carrow, 2002a). Comparing seashore paspalum with other warm-season grasses such as bermudagrass and zoysiagrass, tolerance to scalping is not as good, taking 4 to 6 weeks for recovery (Duncan and Carrow, 2002b). Scalping occurs when excessive green tissue is removed at any one mowing and exposed stems, stolons, and dead leaves create a stubbly, brown appearance (Beard, 2005; McCarty, 2005). Undulations and uneven lay of the land can cause small patches of scalping, but larger areas of scalping are often caused by the failure to follow cultural practices for prevention. Some grasses have better recovering ability and differ in the management practices used to prevent and recover from scalping (Duncan and Carrow, 2002a). However, seashore paspalum is known for its intolerance to scalping. One of the major causes of scalping on seashore paspalum is excessive nitrogen that can cause rapid shoot growth and succulence (Duncan and Carrow, 2002b; Trenholm et al., 2000; McCarty, 2005).

The occurrence of dollar spot disease has been suggested that nitrogen fertility is lean enough for seashore paspalum (Duncan and Carrow, 2002a). The fertilization program should follow similarly to a cool season program, light in the summer and moderate spring and fall fertilization. Thatch buildup and puffiness, leading causes of scalping, can be minimized with a proper fertility program (Duncan and Carrow, 2002a; Duncan, 1998b). To keep to light and proper N rates, applications of 16 to 24 kg N ha^{-1} per application per month are recommended (Duncan, 1998b). In the event scalping does occur from improper fertilization or mowing schedule, calcium nitrate [$Ca(NO_3)_2$] can be used quickly heal affected areas (Duncan and Carrow, 1999).

Selection of an ecotype that tolerates the target mowing height is also important when using seashore paspalum since there is a vast difference between ecotypes (Duncan and Carrow, 1999). Additionally, mowing heights greatly affected the occurrence of scalping, produced shortened internodes, denser canopy, darker green color, and increased turf quality on green ecotypes mowed at three to four mm as compared to Tifgreen bermudagrass mowed at the same height (Duncan, 1999). Seashore paspalum mown at lower mowing heights has also shown to compete with weeds better and also has better fall color retention when mowed at less than 13 mm (Duncan and Carrow, 1999). Seashore paspalum also has good color at low N rates and this may be an indication that a low N rate is practical for this species (Duncan and Carrow, 2002a).

Plant growth regulators (PGRs) are chemicals that alter the growth processes. PGRs that occur naturally in plants include abscisins, auxins, cytokinins, and gibberellins (Beard, 2005).Turf managers often use exogenously applied PGRs on high quality athletic turf to suppress vegetative growth and seed head production (Ferrell et al., 2003).

A reduction in growth also means that mowing frequency can also be reduced (Ferrell et al., 2003); also a reduction in growth could mean that there is a reduction in the chances for scalping since scalping often occurs when excessive green tissue is removed in any one mowing (Beard, 2005; McCarty, 2005). Information on growth regulators for seashore paspalum is limited, but it has been suggested trinexapac-ethyl (TE) applications should be at rates no higher than one half of the labeled rate for bermudagrass and followed by a nitrogen application to reduce bronzing (Duncan and Carrow, 1999). Research at the University of Georgia in Griffin compared TE and paclobutrazol on seashore paspalum and found that TE exhibited symptoms of injury at the lowest rates, while paclobutrazol did not injure seashore paspalum at the highest rates used in the study (Ferrell et al., 2003). The overall hypothesis for this study was increased nitrogen, applications of TE, raising mowing height would decrease the amount of time to recovery when 'Seadwarf' seashore paspalum suffers from a scalping event.

Materials and Methods

Experimental Design

The research was conducted from July to September in 2008 and repeated in 2009 during the same time period at the Turfgrass Research Center, Clemson University, Clemson, SC. Treatments of nitrogen and TE were replicated six times each year and the experiment was repeated in two years on the same site, which are designated by A (original site) and B (new site) for 2009. Mowing height treatments were included using a split plot design. The study was also repeated on an adjacent site the second year. The field research plots were established from sprigging in May 2007 and 2008 with the soil profile constructed to United States Golf Association (USGA) recommendations (USGA, 1993). The experiment design was a factorial combination of nitrogen treatments at 22 and 44 kg ha^{-1} along with TE treatments of 0 and 0.03 kg ai ha^{-1} that were applied in a combined solution weekly after scalping event and continued until recovered. After lowering the mowing height to <2.0 mm to generate severe scalping, each plot was further split into subplots with two mowing heights of 3.2 and 2.5 mm with a plot size of 2.3 by 1.4 meters. The 2x2x2 factorial experiments were performed to examine main and interaction effects of nitrogen rates, TE rates, and mowing height on curing scalping effects of 'SeaDwarf' seashore paspalum. Whole plots for the four combinations of nitrogen rates and TE rates and whole plots for two mowing heights were stripped across each other in a split-block design with six replications (Federer and King, 2007). Data was analyzed using the general linear model procedure of the Statistical Analysis System (SAS 2006). Treatment by year interaction was detected, so results for each year were evaluated and discussed separately. ANOVA was performed to evaluate main and interaction effects of the treatment factors using $\alpha = 0.05$. Since this research reports progress over time for turfgrass quality, bi-weekly data are presented for all treatments in turf cover and quality. Means separation was performed using Fisher's Protected Test for least significant difference (LSD) test with $P < 0.05$.

Data Collection

Turf color was visually rated weekly on a one to nine scale, where one = lowest quality as brown turf and nine = highest quality as dark green turf. Stimpmeter readings were taken on each plot after 10 weeks of treatment to measure ball roll distance. Ball roll distance was measured three times in one direction and three times in the opposite direction, and then averaged for each plot. A mini stimpmeter, one third standard length (Mini-Stimp™, Scientific Golfer, 1971 N. Nowak Ave. Thousand Oaks, CA 91360) was used to keep ball roll within each plot. Averages were then converted to simulate the use of a full length stimpmeter using a multiplication factor of three. Clippings were collected from a 7.7 m^2 area eight weeks after starting treatments from each plot using a walk behind greens mower (Greensmaster 800; The Toro Company, Bloomington, MN), then oven dried at 80^{o}C for 48 h before weighing. Profile samples were collected at 10 WAS using a standard green cup cutter with 10 cm diameter to a depth of 25 cm. Canopy, stolons, rhizomes, and thatch were removed by hand and roots washed using a strainer to be soil free. Roots samples were oven dried (80°C), weighed, ashed in a muffle furnace (550°C) for three hours, and reweighed. Root data are presented as ash-free weight, i.e. oven dry weight minus ash weight (Snyder and Cisar, 2000).

Results/ Discussion

Turf Quality

The effects following the scalping event in 2009 were more severe and longer lasting than in 2008. While TQ in 2008 never fell below the minimally acceptable level of six, the turfgrass in 2009 took until week six for all treatments to have a mean above six (Table 6). There was only one instance throughout the duration of the study where TE had an effect on TQ. In week 8 of 2009, TE decreased TQ 8% compared to applying none. In 2008, N at higher rates increased TQ only during week six, but in 2009, the higher N rate increased TQ at all readings except in week 10, where high N decreased

TQ. Lower mowing height improved TQ as early as week two in 2008, but after week four, the lower mowing height no longer benefit TQ. Data from 2009 differed from 2008, with lower mowing height increasing TQ from weeks four to eight. In 2009 at 10 weeks following treatments, TQ was decreased by the low mowing height, indicating that once turfgrass recovers to acceptable quality, the mowing height should be raised to prevent a drop in TQ.

Clipping Yield, Root Ash, and Ball Roll

Root data was similar in both years for all treatments (Table 7). As expected, clipping yields increased about 20% with the higher N rate in 2009 (Table 7), which was also shown by McCullough et al. (2006a) and Baldwin et al. (2009). Clipping data didn't indicate any conclusive trends on TE or mowing height (Table 8). Ball rolling distances were similar throughout the study indicating no effect with TE or N rate, which contradicts data from Koeritz and Stier (2009) and McCullough et al. (2006b). However, data was similar to Koeritz and Stier (2009), McCullough et al. (2006b) and Stiglbauer et al. (2009), where lower mowing heights increased ball roll distances 5-10%(Table 9).

Conclusions

With scalping being a common problem associated with seashore paspalum, it is important to know the fastest way to recover from a scalping event. In this field study, increasing N promoted the turfgrass and better TQ was observed throughout the experiment. Also, lowering the mowing height benefit the turfgrass until TQ reached acceptable ratings, then declined. Use of higher N rates and a mowing height of 2.54 mm until recovered, and then raising the mowing height to 3.2 mm, may provide a quicker recovery time and alleviate the stress from scalping.

Table 6. Turf quality readings of 'SeaDwarf' seashore paspalum for the effects of nitrogen, TE, and mowing height on recovery from scalping.

Week 2

		Means						
Block	**Year**	**A**	**B**	**C**	**D**	**E**	**F**	**LSD**
	2008	7.0a	5.8c	7.3a	7.3a	7.0a	6.3b	0.5
	2009A	4.5a	5.0a	4.9a	4.9a	4.5a	4.6a	0.6
	2009B	5.6a	5.3a	5.4a	5.5a	5.4a	4.6b	0.5
TE		**.03 kg ai ha^{-1}**			**0 kg ai ha^{-1}**			
	2008	6.7a			6.8a			0.3
	2009A	4.7a			4.8a			0.4
	2009B	5.2a			5.4a			0.3
N Rate		**22 kg ha^{-1}**			**44 kg ha^{-1}**			
	2008	6.7a			6.8a			0.3
	2009A	4.5b			5.0a			0.4
	2009B	5.0b			5.5a			0.3
Mow Ht.		**3.2 mm**			**2.5 mm**			
	2008	6.5b			7.0a			0.3
	2009A	4.7a			4.8a			0.4
	2009B	5.3a			5.3a			0.3

Week 4

		Means						
Block	**Year**	**A**	**B**	**C**	**D**	**E**	**F**	**LSD**
	2008	7.0a	5.5d	5.9cd	6.1bc	6.6ab	6.3bc	0.6
	2009A	6.6a	6.0ab	6.1ab	6.1ab	5.8bc	5.3c	0.6
	2009B	5.9a	5.9a	6.1ab	5.9a	6.1a	6.0a	0.6
TE		**.03 kg ai ha^{-1}**			**0 kg ai ha^{-1}**			
	2008	6.2a			6.3a			0.3
	2009A	5.9a			6.1a			0.4
	2009B	6.0a			6.0a			0.3
N Rate		**22 kg ha^{-1}**			**44 kg ha^{-1}**			
	2008	6.3a			6.2a			0.3
	2009A	5.6b			6.4a			0.4
	2009B	5.7b			6.3a			0.3
Mow Ht.		**3.2 mm**			**2.5 mm**			
	2008	6.4a			6.0b			0.3
	2009A	5.8b			6.2a			0.4
	2009B	5.5b			6.4a			0.3

		Week 6						
		-------------------------- Means --------------------------						
Block	**Year**	**A**	**B**	**C**	**D**	**E**	**F**	**LSD**
	2008	7.4a	7.0a	6.6a	6.9a	6.8a	7.3a	0.8
	2009A	6.5a	6.6a	6.4a	6.1ab	6.0a	5.3b	0.7
	2009B	5.5c	5.4c	6.3b	6.6ab	6.3b	6.9a	0.4
TE		**.03 kg ai ha^{-1}**			**0 kg ai ha^{-1}**			
	2008	7.1a			6.9a			0.5
	2009A	6.1a			6.2a			0.4
	2009B	6.1a			6.2a			0.3
N Rate		**22 kg ha^{-1}**			**44 kg ha^{-1}**			
	2008	6.7b			7.3a			0.5
	2009A	5.8b			6.6a			0.4
	2009B	5.8b			6.5a			0.3
Mow Ht.		**3.2 mm**			**2.5 mm**			
	2008	7.1a			6.9a			0.5
	2009A	6.0a			6.3a			0.4
	2009B	5.6b			6.7a			0.3

		Week 8						
		-------------------------- Means --------------------------						
Block	**Year**	**A**	**B**	**C**	**D**	**E**	**F**	**LSD**
	2008	7.4a	6.5b	6.4b	6.6b	6.5b	6.6b	0.7
	2009A	7.0a	6.9a	6.9a	6.5a	6.4a	6.6a	0.7
	2009B	5.3c	5.5c	6.0b	6.1b	6.1b	7.0a	0.5
TE		**.03 kg ai ha^{-1}**			**0 kg ai ha^{-1}**			
	2008	6.6a			6.7a			0.4
	2009A	6.6a			6.8a			0.4
	2009B	5.8b			6.3a			0.3
N Rate		**22 kg ha^{-1}**			**44 kg ha^{-1}**			
	2008	6.5a			6.8a			0.4
	2009A	6.5b			7.0a			0.4
	2009B	5.5b			6.5a			0.3
Mow Ht.		**3.2 mm**			**2.5 mm**			
	2008	6.7a			6.7a			0.4
	2009A	6.4b			7.0a			0.4
	2009B	5.5b			6.5a			0.3

Block	Year	Week 10						
		---------------------------- Means ----------------------------						
Block	**Year**	**A**	**B**	**C**	**D**	**E**	**F**	**LSD**
	2008	7.8a	7.4a	7.5a	7.5a	7.8a	7.6a	0.5
	2009A	7.0a	6.9a	7.1a	7.3a	6.8a	6.9a	0.6
	2009B	5.9a	5.8a	6.4a	6.0a	6.4a	6.5a	1.0
TE		**.03 kg ai ha^{-1}**			**0 kg ai ha^{-1}**			
	2008	7.6a			7.5a			0.3
	2009A	6.9a			7.1a			0.3
	2009B	6.3a			6.0a			0.6
N Rate		**22 kg ha^{-1}**			**44 kg ha^{-1}**			
	2008	7.5a			7.6a			0.3
	2009A	6.9a			7.1a			0.3
	2009B	5.8b			6.5a			0.6
Mow Ht.		**3.2 mm**			**2.5 mm**			
	2008	7.6a			7.5a			0.3
	2009A	7.6a			6.3b			0.3
	2009B	6.8a			5.5b			0.6

Table 7. Root samples of 'SeaDwarf' seashore paspalum for the effects of nitrogen, TE, and mowing height on recovery from scalping. Samples were burned in a muffle furnace (550 °C) for 3 hrs. and data presented as ash-free weights.

	------------------------ g m^{-2} ---------------------------						
Year	**2008**		**2009A**		**2009B**		**LSD**
	73.6a		87.9a		72.5a		16.3
Block	**A**	**B**	**C**	**D**	**E**	**F**	
	77.0b	75.8b	73.7b	74.7b	64.6b	102.2a	23.0
TE	**.03 kg ai ha^{-1}**			**0 kg ai ha^{-1}**			
	81.2a			74.8a			13.3
N Rate	**22 kg ha^{-1}**			**44 kg ha^{-1}**			
	78.0a			78.0a			13.3
Mow Ht.	**3.2 mm**			**2.5 mm**			
	82.7a			73.3a			13.3

Table 8. Oven dried clipping yields of 'SeaDwarf' seashore paspalum for the effects of nitrogen, TE, and mowing height on recovery from scalping.

		-------------------------- g m^{-2} -------------------------						
Block	**Year**	**A**	**B**	**C**	**D**	**E**	**F**	**LSD**
	2008	5.3ab	6.0a	4.3c	4.5bc	4.4bc	3.8c	1.0
	2009A	2.9c	3.0bc	3.6ab	3.8ab	3.4bc	4.4a	0.9
	2009B	2.0a	2.1a	1.3b	2.0a	1.4b	1.9a	0.5
TE		**.03 kg ai ha^{-1}**			**0 kg ai ha^{-1}**			
	2008	4.5a			5.0a			0.6
	2009A	3.2b			3.9a			0.5
	2009B	1.7a			1.9a			0.3
N Rate		**22 kg ha^{-1}**			**44 kg ha^{-1}**			
	2008	4.6a			4.8a			0.6
	2009A	3.2b			3.8a			0.5
	2009B	1.6b			2.0a			0.3
Mow Ht.		**3.2 mm**			**2.5 mm**			
	2008	2.3b			7.1a			0.6
	2009A	3.5a			3.6a			0.5
	2009B	1.9a			1.7a			0.3

Table 9. Ball rolling distances of 'SeaDwarf' seashore paspalum for the effects of nitrogen, TE, and mowing height on recovery from scalping.

	---------------------------- cm ----------------------------						
Year	2008		2009A		2009B		**LSD**
	353.3a		358.9a		352.8a		8.3
Block	**A**	**B**	**C**	**D**	**E**	**F**	
	351.4bc	341.6c	353.5b	357.7b	369.6a	356.0b	11.7
TE	**.03 kg ai ha^{-1}**			**0 kg ai ha^{-1}**			
	354.5a			355.4a			6.8
N Rate	**22 kg ha^{-1}**			**44 kg ha^{-1}**			
	353.3a			356.7a			6.8
Mow Ht.	**3.2 mm**			**2.5 mm**			
	341.4b			368.6a			6.8

CHAPTER IV. USING AERIFICATION, GROOMING, AND MOWING HEIGHTS TO REDUCE SCALPING OCCURRENCE AND SEVERITY ON 'SEADWARF' SEASHORE PASPALUM PUTTING GREENS

Abstract

As a relative new putting green turfgrass, seashore paspalum's (*Paspalum vaginatum* Swartz.) tendency to scalp at lower mowing heights has not been thoroughly evaluated in the inland southeastern region. A field study was conducted in summer 2008 and repeated twice in summer 2009 (on the same site and a new site) to evaluate cultural practices to reduce occurrence of scalping on 'SeaDwarf' Seashore paspalum golf greens on USGA specification mix with 85% sand 15% peat-moss (v:v). The research greens were established using sprigs in 2007 and 2008. Preventative practice treatments used in the study included aerification frequency paired with either grooming once weekly or no grooming along with two mowing heights of 2.5 or 2.3 mm to observe scalping occurrence and severity. A mowing height of 2.5 mm and one aerification per growing season benefit turf quality for prevention of scalping occurrence and severity. Lower mowing heights (<2.3 mm) may be able to be maintained for a short period of time (one to two weeks) without falling below minimally accepted TQ, but prolonged periods of low mowing heights caused scalping.

Introduction

Scalping has been shown to be a potential problem with seashore paspalum (*Paspalum vaginatum* Swartz) at lower mowing heights often demanded by golfers desiring longer ball roll distances. Seashore paspalum is a perennial C_4 turfgrass originally from South American. It is adapted to saline soils and also exhibits superior drought resistance, wear tolerance, submersion tolerance, salt tolerance, and recuperative potential (Beard, 2005).

Susceptibility of turfgrasses to scalping, as well as recovery ability, differs between species and cultivars, as well as management practices (Duncan and Carrow, 2002a, 2000, 1999). Seashore paspalum is not as tolerant to scalping when compared with other warm-season grasses such as bermudagrass (*Cynodon spp.*) and zoysiagrass (*Zoysia spp.*) and can take 4 to 6 weeks for recovery (Duncan and Carrow, 2002b). Scalping occurs when excessive amounts of green tissue are removed at any one mowing and exposed stems, stolons, and dead leaves create a stubbly, brown appearance (Beard, 2005; McCarty, 2005).

Many times cultural practices are not the only contributor to scalping, undulations and uneven lay of the land can cause small patches of scalping, but larger areas of scalping are often caused by improper fertilization and aerification practices. However, Seashore paspalum is known for its intolerance to scalping. When seashore paspalum is scalped, it maintains and establishes roots and rhizomes, and shoot growth is not top priority for the plant at the time, unlike bermudagrass where shoot growth is very vigorous for the plant (Duncan and Carrow, 2002a). Mowing height also produced shortened internodes, denser canopy, darker green color, and increased turf quality on green ecotypes mowed at three to four mm as compared to 'Tifgreen' bermudagrass mowed at the same height (Duncan, 1999).

One of the major causes of scalping on seashore paspalum is excessive nitrogen that can cause rapid shoot growth and succulence (Duncan and Carrow, 2002b; Trenholm et al., 2000; McCarty, 2005). Occurrence of dollar spot disease has been suggested to indicate the nitrogen fertility program is lean enough for seashore paspalum (Duncan and Carrow, 2002a). The fertilization program should follow similarly to a cool season program, light in the summer and moderate spring and fall fertilization. Thatch buildup and puffiness, leading causes of scalping, can be minimized with a proper fertility program (Duncan and Carrow, 2002a). In the event that scalping does occur from improper fertilization or mowing schedule, calcium nitrate [$Ca(NO_3)_2$] can be used quickly heal affected areas (Duncan and Carrow, 1999).

A vast difference in ecotypes of seashore paspalum makes selection important. Use of ecotypes best suited for a targeted mowing height can increase success with growing seashore paspalum without scalping issues (Duncan and Carrow, 1999). Lower mowing heights have been shown to compete with weeds better and also had better fall color retention when mowed at less than 13 mm (Duncan and Carrow, 1999). Seashore paspalum has shown to have good color at low nitrogen rates and this may be an indication that a low N rate is practical for this species (Duncan and Carrow, 2002a).

Aerification is an important process for the health of turf, especially on putting greens. The aerification process includes pulling cores from the turf area with tines to achieve compaction relief, improvement of the soil mixture in the root zone, improvement of infiltration, percolation, and surface runoff, and to remove excess thatch (Beard, 2005; Duncan and Carrow, 2000). Cores can be removed and soil amendments added to achieve some of these tasks, or they can be incorporated back into the soil without the use of amendments. This can help to disturb the soil for better air and water movement and alleviate compaction, but will not change soil properties or bulk density (Morris, 2008; McCarty, 2005). Aerification is often criticized by golfers because of the disturbances that it causes on a course. On golf greens, it is the most disruptive, yet most beneficial, practice one can do (Duncan and Carrow, 2000). While the turf is recovering to a smooth surface, ball roll and speeds will be affected. Beard (1982) describes thatch as “an intermingled organic layer of dead and living shoots, stems and roots that develops between the zone of green vegetation and the soil surface”. Different turf types including cultivar differences, root zone soil type, and climate conditions affect thatch buildup. Aerification practices are typically done one to three times per year and can very well exceed these numbers. Aerification also impacts water movement, which falls into the soil improvements category, by increasing infiltration and reducing surface runoff (McCarty, 2005). Therefore, the hypothesis for this study was that aerification and grooming the turfgrass, accompanied by a higher mowing height would benefit turfgrass appearance and prevent the occurrence of scalping.

Materials and Methods

Experimental Design

The research was conducted from July to September in 2008 and repeated in 2009 at the Turfgrass Research Center, Clemson University, Clemson, SC on field research plots established from sprigging in May 2007 and 2008 with the soil profile constructed to United States Golf Association (USGA) recommendations (USGA, 1993). The experiment design was a factorial combination of two aerification frequencies, grooming applications, and mowing height applications with a total of four treatments and the plot size was 2.3 by 1.4 meters. The treatments were replicated six times each year and the experiment was repeated in two years 2008 and 2009. The study was also repeated on an adjacent site in 2009. Aerification was applied to the total area in the first week of June, followed by repeat aerifications, on plots receiving three per year, in mid-July and early-August. Grooming treatments were initiated 1 week after the first aerification and mowing height treatments of 2.54 or 2.29 mm initiated one week after the last aerification. Mowing heights were maintained until the end of the growing season. The 2x2x2 factorial experiments were performed to examine main and interaction effects of aerification, grooming, and mowing height on preventing scalping of 'SeaDwarf' seashore paspalum. Whole plots for the four combinations of aerification rates and grooming levels and whole plots for two mowing heights were stripped across each other in a split-block design with six replications (Federer and King, 2007). Data was analyzed using the general linear model procedure of the Statistical Analysis System (SAS 2006). Treatment by year interaction was detected for TQ, so results for each year were evaluated and discussed separately. ANOVA was performed to evaluate main and interaction effects of the treatment factors using $\alpha = 0.05$. Since this research reports progress over time for turfgrass quality, bi-weekly data are presented for all treatments in turf cover and quality. Means separation was performed using Fisher's Protected Test for least significant difference (LSD) test with $P < 0.05$.

Data Collection

Turf quality readings were visually rated on a scale of one to nine, with one equaling brown turf and nine as perfect green turf. Stimpmeter readings were taken on each plot for ball roll distances. Ball roll distances were measured three times in one direction, then three times in the exact opposite direction, then averaged for each plot. A modified stimpmeter, one-third normal length (Mini-Stimp™, Scientific Golfer, 1971 N. Nowak Ave. Thousand Oaks, CA 91360) was used to keep ball rolling within plots. Clippings were collected from a 77 m^2 area from each plot using a walk behind green mower then oven dried at 80^{o}C for 48 hours before weighing. Profile samples were collected using a regular green cup cutter with 10 cm diameter. Canopy, stolons, rhizomes, and thatch were removed by hand and roots washed using a strainer to be soil free. Root samples were oven dried (80°C), weighed, ashed in a muffle furnace (550°C), and reweighed. Root data are presented as ash-free weight, i.e. oven dry weight minus ash weight (Snyder and Cisar, 2000).

Results/ Discussion

Turf Quality

Turf quality readings for prevention of scalping indicated aerification impacted the turf quality on several occasions. This trend was evident almost all reading dates. Mean TQ was higher with one aerification per growing season. Increasing aerification frequency made aerification holes more visible when the mowing heights were decreased. This trend may be the result of plots not being fully recovered from the last aerification on the plots that were treated three times per year. Readings taken in weeks one to four in both 2008 and 2009 showed that increasing aerification frequency decreased TQ (Table 10).

Mowing height was also a frequent source of impact on turf quality (Table 10). Higher mowing heights, in most instances, increased TQ which was also shown by Bunnell et al. (2005) on 'Tifeagle' bermudagrass. Results suggest that mowing heights of 2.54 or 2.29 mm may be able to be maintained for two to three weeks. After five weeks of applying treatments, TQ on plots receiving a mowing height of 2.29 mm declined by an average of 15% and plots with a mowing height of 2.54 mm declined by an average of 10%.

Grooming treatments had little to no effect throughout the duration of the study. Grooming showed that it benefit TQ at only one reading date in 2008 (Table 10).

Root Ash, Clipping Yield, and Ball Rolling

Root data was similar in both years for all treatments (Table 11). Clipping yield was affected by mowing height. The lower mowing height increased clipping yields by 5 to 10%, possibly due to increased shoot density. Aerification frequency also affected clipping yield, decreasing yield by 2% as aerification frequency increased (Table 12).

Ball roll distances showed differences in mowing height and aerification frequency. Lower mowing heights contributed to a 5% further ball rolling distance which was also shown by Kopec et al.(2007) and Koerwitz and Stier (2009). Results also suggest that aerification at lower frequencies can contribute to further ball rolling distances due to increased disruption associated with more frequent aerification (Table13).

Conclusions

Since 'SeaDwarf' seashore paspalum has a high potential for scalping, a study was developed to observe the effects of possible cultural practices to prevent the occurrence. This study indicated mowing height and aerification frequency as the largest contributors to decreasing turf quality. Lower mowing heights can be maintained for short periods of time, up to 2 weeks, before falling below an acceptable level. Aerification once per growing season can help with maintaining turf at lower mowing heights for a longer period of time, although this needs further investigation to analyze the effects of thatch buildup over time since the plots have not been established for a long period of time. Lower mowing heights also contributed to desirable further ball roll. Seashore paspalum may have the potential to provide better ball roll at lower mowing heights for a short duration, such as tournament conditions may require, but not continuously during the growing season.

Table 10. Turf quality readings of 'SeaDwarf' seashore paspalum for the effects of aerification, grooming, and mowing height on reducing scalping occurrence and severity.

		Week 2						
		Means						
Block	**Year**	**A**	**B**	**C**	**D**	**E**	**F**	**LSD**
	2008	6.6a	6.8a	6.6a	6.6a	6.8a	6.9a	0.5
	2009A	5.3a	5.4ab	5.3b	5.8a	5.5ab	5.4ab	0.4
	2009B	5.5a	5.4ab	5.6a	5.3a	5.6a	5.5a	0.7
Mow Ht.		**2.54 mm**			**2.25 mm**			
	2008	7.0a			6.5b			0.3
	2009A	5.6a			5.2b			0.3
	2009B	5.7a			5.3a			0.4
Groomer		**Applied**			**None Applied**			
	2008	6.5b			6.9a			0.3
	2009A	5.3a			5.5a			0.3
	2009B	5.6a			5.4a			0.4
Aerification		**Once Yearly**			**3 Times Yearly**			
	2008	7.0a			6.4b			0.3
	2009A	5.9a			5.0b			0.3
	2009B	6.0a			5.0b			0.4
		Week 3						
		Means						
Block	**Year**	**A**	**B**	**C**	**D**	**E**	**F**	**LSD**
	2008	6.1a	6.1a	6.0a	6.1a	6.1a	6.0a	0.5
	2009A	5.6a	5.8a	5.5a	5.4a	5.5a	5.4a	0.6
	2009B	5.3a	5.0a	4.9a	5.1a	5.4a	5.4a	0.6
Mow Ht.		**2.54 mm**			**2.25 mm**			
	2008	6.6a			5.6b			0.3
	2009A	5.6a			5.5a			0.4
	2009B	5.3a			5.0b			0.3
Groomer		**Applied**			**None Applied**			
	2008	6.0a			6.2a			0.3
	2009A	5.4a			5.6a			0.4
	2009B	5.3a			5.0a			0.3
Aerification		**Once Yearly**			**3 Times Yearly**			
	2008	6.5a			5.7b			0.3

2009A	5.8a	5.3b	0.4
2009B	5.4a	4.9b	0.3

Week 4

Block	Year	A	B	C	D	E	F	LSD
		Means						
Block	Year	A	B	C	D	E	F	LSD
	2008	5.1a	5.0a	5.1a	5.0a	5.0a	5.1a	0.6
	2009A	6.3a	6.1a	5.5b	5.3bc	5.4b	4.9c	0.5
	2009B	5.0ab	4.9ab	4.5b	5.0ab	5.3a	5.1a	0.6
Mow Ht.		2.54 mm			2.25 mm			
	2008	5.6a			4.5b			0.3
	2009A	5.7a			5.5a			0.3
	2009B	5.2a			4.7b			0.4
Groomer		Applied			None Applied			
	2008	5.0a			5.1a			0.3
	2009A	5.6a			5.5a			0.3
	2009B	5.0a			4.9a			0.4
Aerification		Once Yearly			3 Times Yearly			
	2008	5.4a			4.8b			0.3
	2009A	5.7a			5.4b			0.3
	2009B	5.2a			4.8b			0.4

Week 5

Block	Year	A	B	C	D	E	F	LSD
		Means						
Block	Year	A	B	C	D	E	F	LSD
	2008	4.9a	4.8a	4.9a	4.8a	4.8a	4.9a	0.4
	2009A	6.4a	6.1ab	5.5bc	5.5bc	4.9cd	4.8d	0.7
	2009B	4.9cd	5.3abc	4.6d	5.5ab	5.6a	5.0bcd	0.6
Mow Ht.		2.54 mm			2.25 mm			
	2008	5.5a			4.2b			0.2
	2009A	5.7a			5.4a			0.4
	2009B	5.5a			4.8b			0.3
Groomer		Applied			None Applied			
	2008	4.8a			4.8a			0.2
	2009A	5.5a			5.5a			0.4
	2009B	5.2a			5.1a			0.3
Aerification		Once Yearly			3 Times Yearly			
	2008	5.1a			4.5b			0.2
	2009A	5.6a			5.4a			0.4
	2009B	5.2a			5.1a			0.3

Table 11. Root samples of 'SeaDwarf' seashore paspalum for the effects of aerification, grooming, and mowing height on reducing scalping occurrence and severity. Samples were burned in a muffle furnace (550 °C) for 3 hrs. and data presented as ash-free weights.

	-------------------------- g m^{-2} --------------------------						
Year	**2008**		**2009A**		**2009B**		**LSD**
	100.3a		90.5a		89.7a		16.9
Block	**A**	**B**	**C**	**D**	**E**	**F**	
	88.3b	92.3ab	78.8b	91.0ab	114.0a	96.8ab	24.0
Groomer	**Applied**			**None Applied**			
	96.6a			90.4a			13.8
Aerification	**Once Yearly**			**3 Times Yearly**			
	88.9a			98.1a			13.8
Mow Ht.	**2.54 mm**			**2.25 mm**			
	86.8a			100.2a			13.8

Table 12. Oven dried clipping yields of 'SeaDwarf' seashore paspalum for the effects of aerification, grooming, and mowing height on reducing scalping occurrence and severity.

	---------------------------g m^{-2}--------------------------						
Year	**2008**		**2009A**		**2009B**		**LSD**
	137.5a		136.7a		136.5a		2.3
Block	**A**	**B**	**C**	**D**	**E**	**F**	
	138.0a	138.4a	135.4a	135.8a	138.5a	135.3a	3.3
Groomer	**Applied**			**None Applied**			
	137.7a			136.1a			1.9
Aerification	**Once Yearly**			**3 Times Yearly**			
	138.3a			135.6b			1.9
Mow Ht.	**2.54 mm**			**2.25 mm**			
	133.0b			140.9a			1.9

Table 13. Ball rolling distances of 'SeaDwarf' seashore paspalum for the effects of aerification, grooming, and mowing height on reducing scalping occurrence and severity.

	----------------------------cm----------------------------						
Year	**2008**		**2009A**		**2009B**		**LSD**
	137.5a		136.7a		136.5a		2.3
Block	**A**	**B**	**C**	**D**	**E**	**F**	
	138.0a	138.4a	135.4a	135.8a	138.5a	135.3a	3.3
Groomer	**Applied**			**None Applied**			
	137.7a			136.1a			1.9
Aerification	**Once Yearly**			**3 Times Yearly**			
	138.3a			135.6b			1.9
Mow Ht.	**2.54 mm**			**2.25 mm**			
	132.9b			140.9a			1.9

CHAPTER V. ‘DIAMOND’ ZOYSIAGRASS PUTTING GREEN ESTABLISHMENT AFFECTED BY SPRIGGING RATES, NITROGEN SOURCES, AND RATES IN THE SOUTHERN TRANSITION ZONE

Abstract

‘‘Diamond’’ zoysiagrass [*Zoysia matrella* (L.) Merr.] has a potential to become a new warm-season putting green turfgrass. The main objective of the study was to determine factors affecting establishment speed for ‘Diamond’ zoysiagrass as a putting green in the southern transition zone of the United States. Two sprigging rates, three N sources, two N rates, and two mowing heights (2.5 and 3.2 mm) were compared at Clemson University, Clemson, SC. Sprigs of ‘Diamond’ zoysiagrass were planted at rates of 91 or 182 m^3 ha^{-1} in 2007 and repeated in 2008. Urea, ammonium nitrate, and ammonium sulfate were applied at 1.7 or 3.4 g N m^{-2} wk^{-1} from WAS (weeks after sprigging) 3 to 10. Rates were halved from WAS 11 to 12. The N fertilizers were applied as solutions weekly for 16 wks. Weekly percent cover, turf color ratings, root and clipping samples, and ball roll diustances were collected for both years. A significant difference occurred in turf cover between high and low sprig rates. Turf color and cover results show that high rates of fertility associated with high rates of sprigs produced 100% turf cover at WAS 11 and 13 in both years. At the 2.5 mm mowing height, ball roll distances reached to 258 cm in August, 8% further than the best treatment at the 3.2 mm mowing height. ‘‘Diamond’’ zoysiagrass can be established within the same growing season to meet a playable putting green quality but the establishment speed may vary depending on summer monthly temperature fluctuations.

Introduction

Zoysiagrass (*Zoysia* spp.) is a popular warm-season, perennial turfgrasses used on golf courses, sports fields, home lawns, and commercial landscapes from the northern transition zone to the southern region in the United States (Beard, 2002; Engelke and Anderson, 2003). Most commonly used zoysiagrasses in these zones include three species of *Zoysia matrella* ([L.] Merr.), *Zoysia japonica* (Steud.), and *Zoysia pacifica* (Willd. ex Thiele) (Engelke and Anderson, 2003). Zoysiagrass has a wide range of leaf textures and appearances and provides excellent summer month growth performance compared to cool-season turfgrasses in the transition zone. It forms a dense, uniform turf by producing both rhizomes and stolons. It also tolerates stress and unfavorable conditions including lower light intensity (Qian and Engelke, 1999a; Baldwin et al., 2009), moderate to high salinity (Marcum et al., 1998; Qian et al., 2000), moderate drought conditions (Qian and Engelke, 1999b; White et al., 2001), and cold temperatures (Warmund et al., 1998; Patton and Reicher, 2007). High quality of turf appearance under a wide range of environmental conditions has increased zoysiagrass popularity.

There is limited research published about ‘Diamond’ zoysiagrass (*Zoysia matrella* [L.] Merr.) use for putting greens. Zoysiagrass establishment using vegetative plugs or sprigs can take months or even longer to reach adequate coverage and turf quality in comparison with other warm-season turfgrasses (McCarty and Miller, 2002). Furthermore, improper establishment of warm-season turfgrasses may increase plant stress (Richardson and Boyd, 2001) to pest problems, winter hardiness, maintenance costs during establishment, and reduce overall turfgrass quality and function of the desired turf use.

'Diamond' zoysiagrass was developed and released by the Texas Agricultural Experiment Station in April 1996 and registered in 2002 (Engelke et al., 2002). It has adapted throughout the southern region to the transition zone of the United States as a fine turf requiring a medium to high maintenance for use on golf course tees, fairways, sports fields, and home lawns (Engelke et al., 2002). However, among zoysiagrasses, relatively faster establishment rates from plugs have been observed for cultivars Z. japonica than for Z. matrella (Patton et al., 2007). In comparison with sod establishment, zoysiagrass sprig establishment has been shown to be economically feasible and practical. Planting time, fertilizer input, and sprigging rates affect warm-season turfgrass establishment speed and quality depending on location (Richardson and Boyd, 2001; Patton et al., 2004; Guertal, and Hicks, 2009). Increased N fertilization rate during establishment can hasten vegetative establishment. Richardson and Boyd (2001) reported a 5 to 10% increase in turf cover of 'Meyer' zoysiagrass (*Zoysia japonica* Steud.) 120 d after sprigging at a low rate of 18 m^3ha^{-1} when monthly N was increased from 0 to 2.5 g m^{-2}. There is a lack of published research regarding N rates, N sources, and sprigging rates for warm-season putting green establishment. However, a few seeding rates studies about zoysiagrass establishment were reported. Portz et al. (1981) recommended seeding rates of 3.8 to 9.8 g m^{-2} zoysiagrass, whereas Landry and Choi (1995), in greenhouse studies, found 9.8 g m^{-2} produced the highest shoot and root growth. Carroll et al. (1996) reported that sprigs (using sprigging rates of 19 or 31 m^3ha^{-1}) of `Meyer' zoysiagrass treated with urea-N, a biostimulator, and one of three preemergence herbicides or one of two postemergence herbicides hastened establishment in two field studies. Monthly rate of N at 4.9 g m^{-2} applied during the growing season had no influence on sprig establishment in the first year, but slightly increased (+5%) turf cover the second year with a higher sprigging rate of 31 $m^3 ha^{-1}$. Overall, sprigging rate recommendations for establishment are lacking or inclusive. Therefore, the objective of this field study was to evaluate 'Diamond' zoysiagrass responses to sprigging rate and fertilizer N source and rate during establishment of putting greens in the transition zone of the United States. Turf cover and color were monitored weekly after sprigging and clipping and root mass were measured after complete cover was achieved. In addition, ball roll was measured after complete cover for two mowing heights.

Materials and Methods

Establishment and Treatments

Research was conducted from May to September 2007 and repeated in 2008 at the Turfgrass Research Center, Clemson University, Clemson, SC on field research plots with the soil profile constructed to United States Golf Association (USGA) recommendations (USGA, 1993) with 85% sand and 15% peat-moss (v:v). The experiment design was a factorial combination of two sprigging rates, two N rates, and three N sources with a total of 12 treatments. Plot size was 2.75 by 1 meter. Treatments were replicated three times each year and the experiment was repeated over two years at two adjacent sites. For the higher sprigging rate treatments, each plot (2.75 m side) was further split into subplots with the two mowing heights of 2.5 and 3.2 mm, which are common mowing height ranges for golf putting greens. Due to the lower turf cover to avoid scalping, the 2.5 mm mowing height was not implemented on the plots with the lower sprigging rates.

‘Diamond’ zoysiagrass sprigs were harvested less than 15 hours before planting by New Life Turf, Norway, SC. Sprigs were planted by hand on 17 May 2007 and 16 May 2008 at rates of 91 m^3 ha^{-1} and 182 m^3 ha^{-1}, which represent a recommended rate and two-fold of the recommended rate for putting green establishment. After sprigging, in order to increase sprig and soil contact the plots were cultivated in two directions with a 5 cm spacing disk. Plots were heavily topdressed (>1 mm) immediately after sprigging with the 85:15 (sand: peat-moss; v:v) putting green sand similar as the green root zone mix. After topdressing, plots were rolled several times in different directions. Water was applied as needed to avoid any water stress during the whole establishment period of 16 weeks. A granular starting fertilizer of 17-7-14 of N (100% quick release N), P, and K was applied at 4.9 g N m^{-2} two wks prior the establishment and additional applications of liquid forms of K and P at 4.0 g K m^{-2} and 2.2 g P m^{-2}, respectively at WAS 6. Urea, ammonium nitrate, and ammonium sulfate were applied at 1.7 or 3.4 g N m^{-2} wk^{-1} from WAS 3 to 10. From WAS 11 to 12, half rates of N were applied.

In both years, plots were first mowed in late June (40 days after sprigging) at a height of 12.7 mm. Thereafter, plots were mowed three times per wk for four wks at 6.4 mm and then mowed five times per wk at 3.2 mm. Two wks later, half of each plot with the higher sprigging rate were mowed to 2.5 mm.

Treatment abbreviations used to present the data are as follows: the number either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 m^3 ha^{-1} as the higher rate and 91 = 91 m^3 ha^{-1} as the lower rate; the single upper case letter indicates the three N sources as U= urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N m^{-2} wk^{-1} from WAS 3 to 10 and 1.7 = the lower rate of 1.7 g N m^{-2} from WAS 11 to 12.

Data Collection

Turf color readings were visually quantified on a one to nine scale, where one = lowest quality as brown turf and nine = highest quality as dark green turf. Turf cover readings were taken as percentage of green turf tissue cover weekly using a line intersec grid. The grid was an 18.5 cm by 18.5 cm frame made from 2.5 cm diameter PVC pipe with strings evenly spaced to form 100 equal small squares (1.85 by 1.85 cm). During data collection, the grid was randomly placed on each plot and grid squares with or without green turfgrass shoots or leaves were counted to determine percent cover from each reading. During each reading, Stimpmeter readings were taken on each plot for ball rolls. Ball rolls were measured three times in one direction and three times in the opposite direction, then averaged for each plot. A shortened stimpmeter (Mini-Stimp™, Scientific Golfer, 1971 N. Nowak Ave. Thousand Oaks, CA 91360) was used to keep ball roll within each plot. Clippings were collected from each plot using a walk behind green mower (Greensmaster 800; The Toro Company, Bloomington, MN), then were oven dried at 80^{o}C for 48 h before weighing. Root samples were collected using a standard green cup cutter with 10 cm diameter to a depth of 25 cm. Canopy, stolons, rhizomes, and thatch were removed by hand and roots were washed using a strainer to be soil free. Roots samples were oven dried (80°C), weighed, ashed in a muffle furnace (550°C) for three hrs, and reweighed. Root data are presented as ash-free weight, i.e. oven dry weight minus ash weight (Snyder and Cisar, 2000).

Data Analysis

Treatments were arranged in a restricted split-block design with three replications in each year. Nitrogen sources and rate treatments were arranged in a randomized complete block design, while two sprigging rates and two mowing heights were the split-block factors (Bunnell et al., 2005; Baldwin et al., 2009). Treatment effects were evaluated using analysis of variance (ANOVA) within SAS (SAS Institute, 2001). Yearly interactions occurred, therefore, the two year data are presented separately. There were no other significant interactions between N sources but the rates were significant. Since this research reports weekly progress in turfgrass establishment, weekly data were presented for all treatments in turf cover and quality. Means separation was performed using Fisher's Protected Test for least significant difference (LSD) test with $P < 0.05$.

Results/ Discussion

Turf Cover and Color

Interactions occurred between most parameters measured for both years; therefore the data are presented separately by years (Tables 15, 16, and 17). Yearly interactions occurred most likely due to the temperature variations in 2007 and 2008 in the Clemson area, SC. Between WAS 1 to 2, 13 d with maximum temperatures below 29.4 ^{o}C in 2008 occurred while there were only 8 d in 2007. Also, August average maximum temperature in 2007 was 35.5 ^{o}C compared with 31.8 ^{o}C in 2008 (Long, 2006; Baldwin, 2008; Sarvis, 2008) although no degree day differences were found between the two years. Relatively cooler days in the early summer 2008 slowed the establishment speed for ‘Diamond’ zoysiagrass.

Higher sprigging rates significantly enhanced turf cover starting at WAS 3 in both 2007 and 2008. For putting green establishment, turf cover must reach 100% in order to assure proper ball rolling on a smooth green surface. ‘Diamond’ zoysiagrass reached 100% turf cover for all treatments at WAS 11 in 2007 and WAS 12 in 2008. By WAS 12 and 13, regardless of N sources and rates, turf cover reached to 100% in 2007 and 2008, respectively. It is worthy to note that higher sprigging rates provided two times of turf cover as the lower sprigging rate starting WAS 3, although the difference between two sprigging rates in turf cover became closer starting at WAS 4 (Table 15 and 16). All higher sprigging rate treatments reached > 90% turf cover with high N rates at WAS 7 in 2007 and WAS 11 in 2008.

The total annual N rates applied were 35.5 and 20.2 g m^{-2} yr^{-1} including a starting fertilizer of 4.88 g N m^{-2} applied two wks before sprigging. Nitrogen rates of 0.3 to 4.9 g N m^{-2} wk^{-1} were reported acceptable for ‘TifEagle’ bermudagrass putting green establishment (Guertal and Evans, 2006). As a shade tolerant turfgrass, ‘Diamond’ zoysiagrass may require an even a lower N input if shaded (Qian and Engelke, 1999a;

Baldwin et al., 2009). During the two-year establishment study, it was suggested that N demand for 'Diamond' zoysiagrass was not as high as a hybrid bermudagrass putting green.

Higher N rates enhanced turf color regardless of N sources and sprigging rates, particularly at later WAS in both years (Table 17). In the 2-year study, N sources did not affect turf cover and color, which agreed with findings by Guertal and Hicks (2009) who indicated that nitrogen sources (either as NH_4NO_3 or $Ca(NO_3)_2$) rarely affected percentage turf cover, shoot density, or dry weight of stolons and rhizomes of 'Tifway' or 'Tifsport' bermudagrasses (*C. dactylon x C. transvaalensis* Pers. L.). However, for cool-season turfgrass putting greens, N sources seem affecting turf growth and performance. Schlossberg and Schmidt (2007) reported that N rates >24.4 g m^{-2} yr^{-1} containing >50% NH_4–N significantly enhanced shoot growth and color, when compared to equal rates containing 50% NO_3–N. Frequent fertilization with NH_4–N at annual rates >24.4 g m^{-2} maximized canopy color and tissue nutrient levels of a putting green with a mixture of bentgrass (*Agrostis stolonifera* L.)/annual bluegrass (*Poa annua* L.). Guertal and Evans (2006) reported increasing N from 0.3 to 4.8 g N m^{-2} wk^{-1}reduced TifEagle bermudagrass turf cover in year one of the three-year study. In year two, turf cover was maximized at N rates from 3.6 to 4.3 g N m^{-2} wk^{-1} on a loamy sand native soil as a putting green. A slight negative impact was also observed at WAS 6 in the 2007 establishment study using both lower and higher N rates of ammonium sulfate (182-S-3.4 and 182-S-1.7) with turf color rating dropping 6.0 to 5.3 with a possibility of fertilizer burn but it only lasted for one wk (Table 17). However, the complicated roles of N sources and rates for warm-season turfgrasses growth and performance, including ‘Diamond’ zoysiagrass putting green establishment associated environmental issues and other nutrient elements need further investigation (Guertal, 2006, 2008; Erickson et al., 2008; Liu et al., 2008; Snyder et al., 2008).

Root Weight, Clipping Yield, and Ball Rolling

Differences did not occur in ash-free root weight with samples collected at WAS 14 in both years (Table 18). Differences were also not found in the following spring green-up and summer month performance (data not shown). Root weight results might imply that establishment with different sprigging rates and N rates would not have residual effects on the future seasons. Although there were no significant differences in ash-free root weight, the broad range of root weight data might be affected by excluded stolons, rhizomes, or other biomass. However, the yearly interaction was significant for root weight and the first year had much higher root weight presumably due to relatively higher temperatures in early summer 2007.

Differences were found in clipping yields for both mowing heights and both years. Under 3.2 mm mowing height in both years, 182-S-3.4 had increased clipping yield compared to treatments with a lower sprigging rate except 91-S-3.4 in 2007. However, all lower N rate treatments had a reduced clipping yield at 2.5 mm mowing height. In order to avoid scalping ‘Diamond’ zoysiagrass, the lower sprigging rates were not mowed at the lower mowing height due to a lack of information of ‘Diamond’ zoysiagrass response to a mowing height of 2.5 mm. In 2008, clipping yields differed when compared with the other treatments at both 2.5 and 3.2 mm mowing heights corresponding with different N rates (Table 19).

Ball roll distances are an important characteristics for playability of a putting green (Beard, 2002). In both years a lack of significance was found for ball rolling at the 2.5 mm mowing height, but in 2007, 91-S-1.7 and 91-U-1.7 showed significantly increased ball roll distance compared with 182-U-3.4 and 182-N-3.4 (Table 19). In 2008, 91-N-1.7 had a further ball rolling than all treatments with higher sprigging rates and N rates except 182-U-1.7. The trend of higher sprigging rates slowed ball roll in both years with a possibility a faster thatch accumulation although thatch data were not collected. 'Diamond' zoysiagrass putting green ball rolling needs to be further enhanced and the current furthest ball rolling was still less than an acceptable distance for tournament purposes.

Conclusions

'Diamond' zoysiagrass has shown to be a new alternative warm-season putting green turfgrass. Putting green turf quality can be reached within a single season in the transition zones and establishment speed can vary according to summer temperature fluctuations. Proper sprigging rates and nitrogen rates play important roles in 'Diamond' zoysiagrass putting green establishment in the southern transition zone of the United States. 'Diamond' zoysiagrass establishment speed can be hastened by using higher sprigging rates within a time frame of 10 to 12 wks. It was tested in both years that 'Diamond' zoysiagrass can be mowed as low as 2.5 mm without scalping or winter month survival problems at a sprigging rate of 182 m^3 ha^{-1}. In both years of the study, higher sprigging rates benefited turf cover while higher N rates benefited turf color. Nitrogen sources did not play significant roles in ‘Diamond’ zoysiagrass establishment. However, rates combined with higher sprigging rates negated ball roll possibly due to a thickened thatch layer and further ball rolling enhancement of ‘Diamond’ zoysiagrass putting green is needed. Recommendations for ‘Diamond’ zoysiagrass putting green establishment in the transition zone may include a sprigging rate greater than 91 m^3 ha^{-1} , a total N input between 20 and 35 g m^{-2} yr^{-1}, and a time frame of 10 to 12 wks. Finally, within 90-120 days '‘Diamond’' may be successfully established as putting green turf using a relatively low rates of sprigs and quick release N sources.

Table 14. Weekly percent cover of ''Diamond'' zoysiagrass established on 17 May 2007 using sprigs at two sprigging rates, three N sources and two N rates with readings started from WAS 3.

Trt/WAS	3	4	5	6	7	8	9	10	11	12	13
182-N-3.4[z]	50.0 a[y]	66.0 a	62.7 a	88.0 a	90.3 a	93.3 a	95.0 ab	96.3 a	99.3 a	100.0 a	100.0
182-N-1.7	51.7 a	62.3 a	60.7 ab	87.7 a	86.0 a	91.3 a	92.3 b	95.7 a	99.7 a	100.0 a	100.0
91-N-3.4	26.7 b	52.7 b	48.3 c	56.7 b	70.0 b	75.3 b	81.7 c	85.0 b	93.7 c	98.0 b	100.0
91-N-1.7	24.7 b	51.7 b	44.3 c	51.0 b	68.3 b	73.0 b	80.0 c	82.3 b	96.3 bc	98.0 b	100.0
182-S-3.4	46.7 a	68.0 a	65.3 a	89.7 a	91.3 a	95.0 a	96.3 a	99.7 a	100.0 a	100.0 a	100.0
182-S-1.7	50.7 a	65.3 a	63.0 a	85.3 a	88.3 a	94.0 a	94.7 ab	98.3 a	99.7 a	100.0 a	100.0
91-S-3.4	24.7 b	52.7 b	44.7 c	52.3 b	67.7 b	74.7 b	79.0 c	87.3 b	94.7 bc	97.0 bc	100.0
91-S-1.7	23.7 b	50.0 b	44.0 c	52.0 b	67.3 b	72.7 b	79.0 c	82.0 b	95.3 bc	96.7 c	100.0
182-U-3.4	49.0 a	67.7 a	67.3 a	90.3 a	91.3 a	93.7 a	95.0 ab	98.0 a	100.0 a	100.0 a	100.0
182-U-1.7	47.3 a	63.7 a	59.0 ab	85.0 a	89.0 a	91.3 a	93.3 ab	96.7 a	99.7 a	100.0 a	100.0
91-U-3.4	26.0 b	55.0 b	46.3c	53.0 b	67.7 b	75.0 b	79.3 c	82.7 b	95.0 bc	97.7 bc	100.0
91-U-1.7	28.0 b	55.7 b	50.7 bc	60.0 b	68.7 b	75.0 b	79.7 c	83.7 b	96.0 bc	97.7 bc	100.0

[z] Treatment abbreviations:

The number either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 m^3 ha^{-1} as the higher rate and 91 = 91 m^3 ha^{-1} as the lower rate; the single upper case letter indicates the three N sources as U= urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N m^{-2} wk^{-1} from WAS 3 to 10 and 1.7 = the lower rate of 1.7 g N m^{-2} from WAS 11 to 12.

[y] Values in columns followed by the same letter are not significantly different at $P \leq 0.05$ using Fisher's Protected LSD.

Table 15. The weekly percent cover of ''Diamond'' zoysiagrass established on 16 May 2008 using sprigs at two sprigging rates, three N sources and two N rates with readings started from WAS 5.

Trt[z]/ WAS	5	6	7	8	9	10	11	12	13	14	15	16
182-N-3.4	40.3 a[y]	52.7 a	65.3 a	72.3 ab	85.0 a	88.0 a	96.3 a	98.7 a	100.0 a	100.0 a	100.0 a	100.0
182-N-1.7	29.7 abc	47.3 a	59.7 a	71.0 ab	81.7 a	87.7 a	95.6 a	98.0 a	100.0 a	100.0 a	100.0 a	100.0
91-N-3.4	15.3 cde	26.7 cd	39.3 b	45.7 d	63.3 ab	56.7 b	82.3 b	81.3 bc	87.7 b	93.7 c	97.7 b	100.0
91-N-1.7	22.0 bcde	31.0 cd	43.0 b	52.3 bcd	51.0 b	52.0 b	85.0 b	76.3 d	84.3 c	92.0 c	97.3 b	100.0
182-S-3.4	29.0 abcd	44.7 ab	65.7 a	79.7 a	86.0 a	89.7 a	99.7 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0
182-S-1.7	34.7 ab	44.0 ab	63.7 a	78.0 a	85.7 a	85.3 a	98.3 a	99.3 a	100.0 a	100.0 a	100.0 a	100.0
91-S-3.4	16.3 cde	28.3 cd	45.0 b	52.3 bcd	80.3 a	52.3 b	82.0 b	77.3 cd	84.3 c	92.0 c	97.7 b	100.0
91-S-1.7	21.3 bcde	35.0 bc	45.3 b	55.7 bcd	67.3 ab	51.0 b	87.3 b	77.0 cd	84.0 c	93.0 c	97.7 b	100.0
182-U-3.4	36.3 a	50.0 a	66.7 a	82.7 a	85.3 a	90.3 a	98.0 a	99.7 a	100.0 a	100.0 a	100.0 a	100.0
182-U-1.7	40.7 ab	54.0 a	63.7 a	68.3 abc	78.7 a	85.0 a	96.7 a	98.7 a	100.0 a	100.0 a	100.0 a	100.0
91-U-3.4	12.3 e	22.3 d	36.7 b	43.7 d	64.7 ab	60.0 b	83.7 b	85.0 b	90.7 b	96.0 b	99.7 a	100.0
91-U-1.7	13.0 de	23.7 d	41.7 b	50.0 cd	73.7 ab	53.0 b	82.7 b	77.3 cd	84.0 c	93.3 c	97.7 b	100.0

[z] Treatment abbreviations:
The number either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 $m^3 ha^{-1}$ as the higher rate and 91 = 91 $m^3 ha^{-1}$ as the lower rate; the single upper case letter indicates the three N sources as U= urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N m^{-2} wk^{-1} from WAS 3 to 10 and 1.7 = the lower rate of 1.7 g N m^{-2} from WAS 11 to 12.

[y] Values in columns followed by the same letter are not significantly different at $P \leq 0.05$ using Fisher's Protected LSD.

Table 16. Turf color readings of ''Diamond'' zoysiagrass established using sprigs at two sprigging rates, three N sources and two N rates in 2007 and 2008 with readings started from WAS 3 to 12.

Trt/WAS	3	4	5	6	7	8	9	10	11	12
					2007					
182-N-3.4[z]	6.0 a[y]	5.7 ab	6.0 a	5.3 bc	7.0 ab	7.3 abc	8.0 a	8.0 a	8.0 a	8.0 a
182-N-1.7	4.7 b	6.0 a	4.7 cd	5.7 ab	6.7 ab	7.7 ab	7.0 c	7.3 ab	7.3 ab	7.3 ab
91-N-3.4	6.0 a	5.3 abc	5.3 abc	6.0 a	7.33 a	8.0 a	8.0 a	8.0 a	8.0 a	8.0 a
91-N-1.7	5.0 b	5.3 abc	5.3 abc	5.7 ab	6.7 ab	7.7 ab	7.0 c	7.3 ab	7.3 ab	7.3 ab
182-S-3.4	6.0 a	6.0 a	6.0 a	5.3 bc	7.3 a	8.0 a	8.0 a	7.7 ab	7.7 ab	7.7 ab
182-S-1.7	5.0 b	6.0 a	6.0 a	5.3 bc	7.0 ab	7.0 bcd	7.0 c	7.3 ab	7.3 ab	7.3 ab
91-S-3.4	2.7 c	4.3 c	4.3 c	4.7 d	6.7 ab	7.0 bcd	8.0 a	7.7 ab	7.7 ab	7.7 ab
91-S-1.7	2.3 c	4.3 c	4.3 c	5.0 cd	6.7 ab	6.7 cd	7.0 c	7.0 b	7.0 b	7.0 b
182-U-3.4	2.7 c	4.7 bc	4.7 bc	4.7 d	5.3 b	6.3 d	8.0 a	8.0 a	8.0 a	8.0 a
182-U-1.7	2.3 c	4.3 c	4.3 c	5.0 cd	5.7 ab	6.3 d	7.0 c	7.0 b	7.0 b	7.0 b
91-U-3.4	2.3 c	4.7 bc	4.7 bc	5.0 cd	6.0 ab	6.7 cd	8.0 a	8.0 a	8.0 a	8.0 a
91-U-1.7	2.7 c	4.7 bc	4.7 bc	4.7 d	5.7 ab	6.7 cd	7.3 c	7.3 ab	7.3 ab	7.3 ab
					2008					
182-N-3.4[z]	2.3 ab[y]	3.3 abc	4.0 bcd	4.0 b	5.7 ab	6.3 cd	7.3 ab	8.0 a	8.0 a	8.0 a
182-N-1.7	2.0 abc	3.0 abc	4.7 ab	4.7 ab	5.3 b	6.7 bc	7.0 b	7.3 bc	7.0 c	7.0 c
91-N-3.4	2.7 a	4.0 a	5.0 a	5.0 a	6.3 a	7.7 a	7.7 ab	8.0 a	8.0 a	8.0 a
91-N-1.7	2.3 ab	3.7 ab	4.3 abc	4.7 ab	5.3 b	6.3 cd	7.7 ab	7.3 bc	7.7 ab	7.7 ab
182-S-3.4	2.3 ab	3.7 ab	4.3 abc	4.7 ab	6.3 a	7.3 ab	8.0 a	7.7 ab	8.0 a	8.0 a
182-S-1.7	2.7 a	3.3 abc	4.3 abc	4.7 ab	5.7 ab	6.3 cd	7.3 ab	7.3 bc	7.0 c	7.0 c
91-S-3.4	2.0 abc	3.3 abc	4.0 bcd	4.3 ab	5.7 ab	6.0 cd	7.6 ab	7.7 ab	8.0 a	8.0 a
91-S-1.7	1.3 cd	2.7 bc	3.7 cde	4.3 ab	5.3 b	5.7 de	7.0 b	7.0 c	7.0 c	7.0 c
182-U-3.4	1.7 bcd	3.3 abc	3.7 cde	4.7 ab	5.7 ab	6.7 bc	8.0 a	8.0 a	8.0 a	8.0 a
182-U-1.7	1.3 cd	2.3 c	4.0 bcd	4.3 ab	5.3 b	6.0 cd	7.3 ab	7.0 c	7.0 c	7.0 c
91-U-3.4	1.0 d	2.7 bc	3.3 de	4.3 ab	5.7 ab	6.3 cd	7.3 ab	8.0 a	8.0 a	8.0 a
91-U-1.7	1.7 bcd	3.0 abc	3.0 e	4.0 b	5.0 b	5.0 e	7.3 ab	7.0 c	7.3 bc	7.3 bc

[z] Treatment abbreviations: The number either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 $m^3\,ha^{-1}$ as the higher rate and 91 = 91 $m^3\,ha^{-1}$ as the lower rate; the single upper case letter indicates the three N sources as U= urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N $m^{-2}\,wk^{-1}$ from WAS 3 to 10 and 1.7 = the lower rate of 1.7 g N m^{-2} from WAS 11 to 12. [y] Values in columns followed by the same letter are not significantly different at $P \leq 0.05$ using Fisher's Protected LSD.

Table 17. Root samples of established ''Diamond'' zoysiagrass were collected on 15 August 2007 and 19 August 2008 and burned in a muffle furnace (550°C) for 3 hrs. The data are presented as ash-free weights.

	---------- g m^{-2} --------	
Trt/Root wt.	2007	2008
182-N-3.4 [z]	514.8 a [y]	237.7 a [y]
182-N-1.7	730.0 a	317.0 a
182-S-3.4	790.7 a	213.5 a
182-S-1.7	764.8 a	411.3 a
182-U-3.4	738.1 a	339.1 a
182-U-1.7	730.8 a	223.7 a
91-N-3.4	520.1 a	282.2 a
91-N-1.7	866.7 a	427.4 a
91-S-3.4	480.9 a	226.6 a
91-S-1.7	472.8 a	232.6 a
91-U-3.4	394.7 a	270.4 a
91-U-1.7	540.3 a	227.1 a

[z] Treatment abbreviations:

The number either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 m^3 ha^{-1} as the higher rate and 91 = 91 m^3 ha^{-1} as the lower rate; the single upper case letter indicates the three N sources as U= urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N m^{-2} wk^{-1} from WAS 3 to 10 and 1.7 = the lower rate of 1.7 g N m^{-2} from WAS 11 to 12.

[y] Values in columns followed by the same letter are not significantly different at $P \leq 0.05$ using Fisher's Protected LSD.

Table 18. Oven-dried clipping yields of established ‘‘Diamond’’ zoysiagrass collected on 7 September 2007 and 10 September 2008 by using a walk-behind mower.

	g m^{-2}			
	2007		2008	
Trt/mowing ht.	3.2 mm	2.5 mm	3.2 mm	2.5 mm
182-N-3.4 [z]	2.42 ab [y]	2.86 a [y]	6.08 ab [y]	3.86 a [y]
182-N-1.7	2.04 abcd	1.94 ab	4.35 de	2.21 b
182-S-3.4	2.60 a	2.44 ab	6.58 a	3.41 a
182-S-1.7	2.00 abcd	2.08 ab	3.26 f	2.26 b
182-U-3.4	2.15 abc	2.45 ab	6.26 ab	3.79 a
182-U-1.7	1.69 abcd	1.51 b	4.06 def	2.60 b
91-N-3.4	1.45 cd		5.41 bc	
91-N-1.7	1.16 d		3.19 f	
91-S-3.4	2.01 abcd		4.53 cd	
91-S-1.7	1.16 d		3.07 f	
91-U-3.4	1.60 bcd		4.81 cd	
91-U-1.7	1.23 cd		3.39 ef	

[z] Treatment abbreviations:

The number either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 m^3 ha^{-1} as the higher rate and 91 = 91 m^3 ha^{-1} as the lower rate; the single upper case letter indicates the three N sources as U= urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N m^{-2} wk^{-1} from WAS 3 to 10 and 1.7 = the lower rate of 1.7 g N m^{-2} from WAS 11 to 12.

Table 19. Ball rolling distances of established ''Diamond'' zoysiagrass by using a modified stimpmeter and the data were collected on 31 August 2007 and 20 September 2008.

	cm					
	2007			2008		
Trt/mowing ht.	3.2 mm		2.5 mm	3.2 mm		2.5 mm
182-N-3.4 [z]	194.6	bc [y]	240.1	188.0	cd [y]	251.4
182-N-1.7	204.0	abc	242.4	205.2	bcd	249.1
182-S-3.4	205.0	abc	235.2	204.6	bcd	241.5
182-S-1.7	209.9	ab	244.4	206.5	bcd	261.5
182-U-3.4	185.6	c	238.0	178.4	d	249.5
182-U-1.7	205.4	abc	239.7	219.4	ab	258.0
91-N-3.4	215.9	ab		209.9	abc	
91-N-1.7	217.2	ab		237.9	a	
91-S-3.4	207.9	abc		213.9	abc	
91-S-1.7	219.5	a		230.3	ab	
91-U-3.4	213.1	ab		213.8	abc	
91-U-1.7	223.9	a		222.1	ab	

[z] Treatment abbreviations:

The number either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 $m^3 ha^{-1}$ as the higher rate and 91 = 91 $m^3 ha^{-1}$ as the lower rate; the single upper case letter indicates the three N sources as U= urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N m^{-2} wk^{-1} from WAS 3 to 10 and 1.7 = the lower rate of 1.7 g N m^{-2} from WAS 11 to 12.

[y] Values in columns followed by the same letter are not significantly different at $P \leq 0.05$ using Fisher's Protected LSD.

APPENDICES

Appendix A

Illustrations

Figure 1. Comparison of seashore paspalum and '‘Diamond’' zoysiagrass putting green surface.

Figure 2. Sprigging of 'SeaDwarf' Seashore paspalum in Clemson, SC, May 17, 2007.

Figure 3. Seashore paspalum establishment (4 &6 WAS) in 2007. Low sprigging rate (91 m^3 ha^{-1}) pictured left and high sprigging rate (182 m^3 ha^{-1}) right.

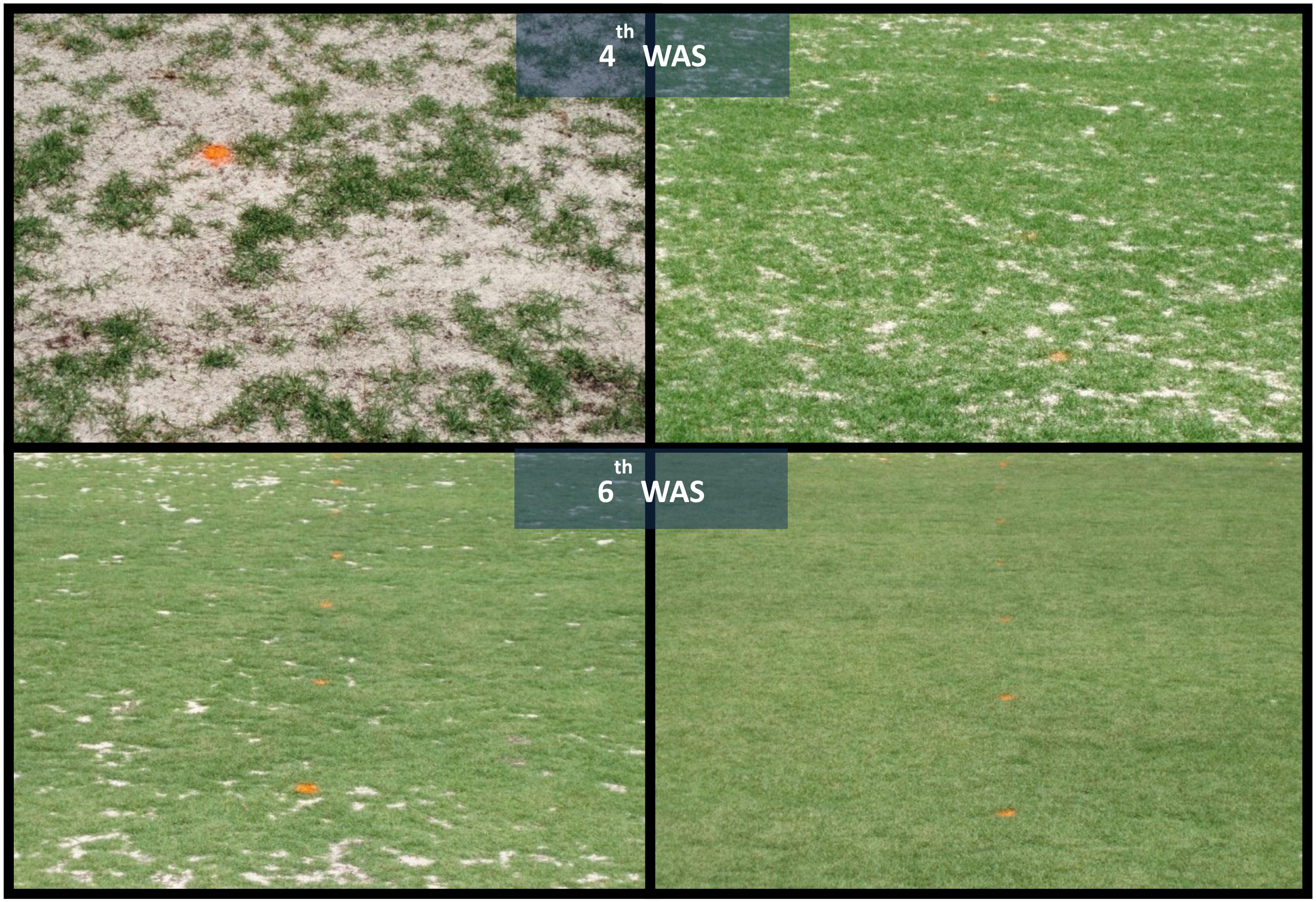


Figure 4. Seashore paspalum establishment (8 &10 WAS) in 2007. Low sprigging rate (91 m^3 ha^{-1}) pictured left and high sprigging rate (182 m^3 ha^{-1}) right.

Figure 5 Treatments on seashore paspalum recovery from scalping after 3 weeks of treatment in 2008.

Figure 6 Seashore paspalum treatments for reducing scalping occurrence and severity after 4 weeks of treatment in 2009.

Figure 7 ''Diamond'' zoysiagrass establishment (6 & 8 WAS) in 2007. Low sprigging rate (91 m^3 ha^{-1}) pictured left and high sprigging rate (182 m^3 ha^{-1}) right.

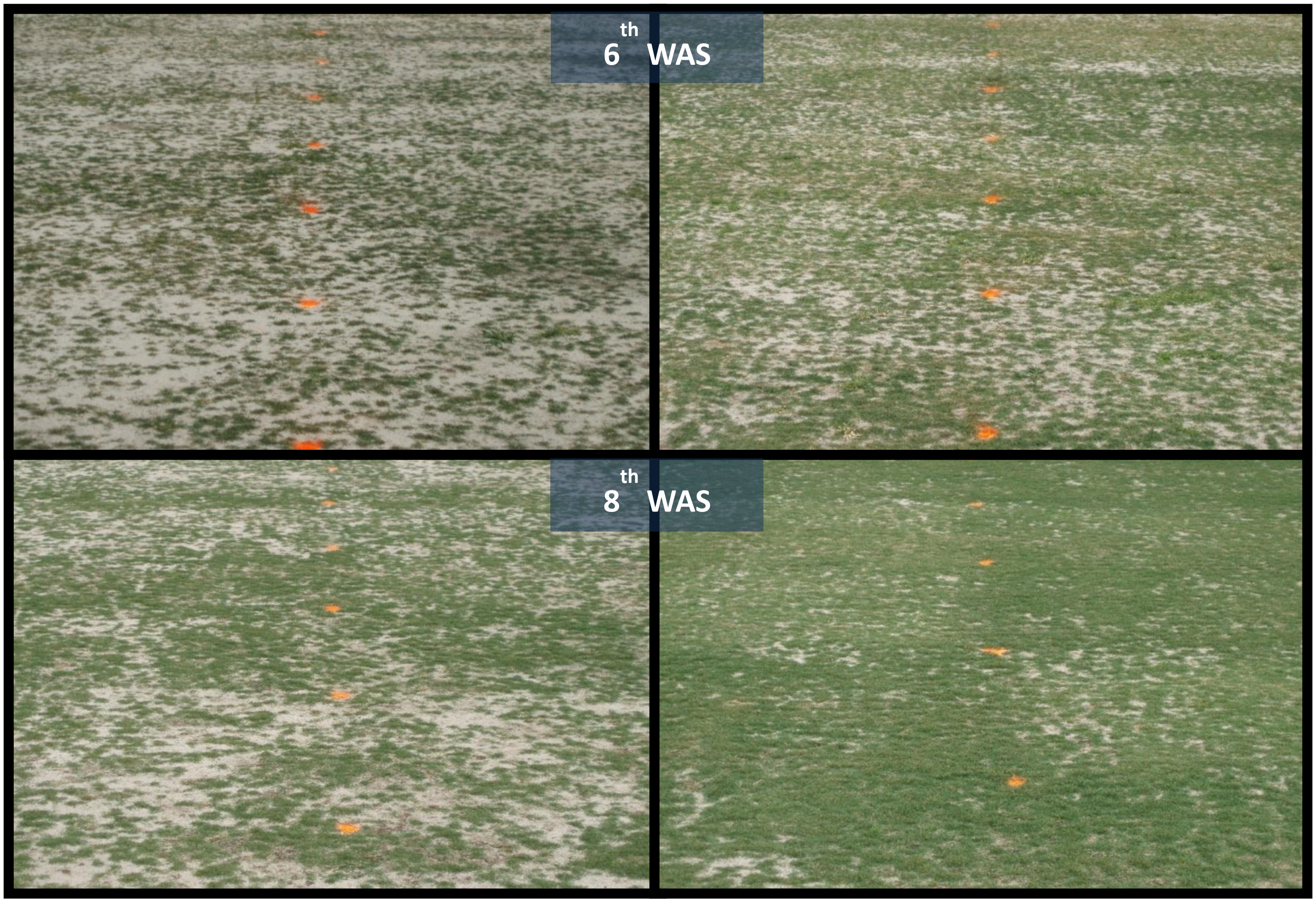
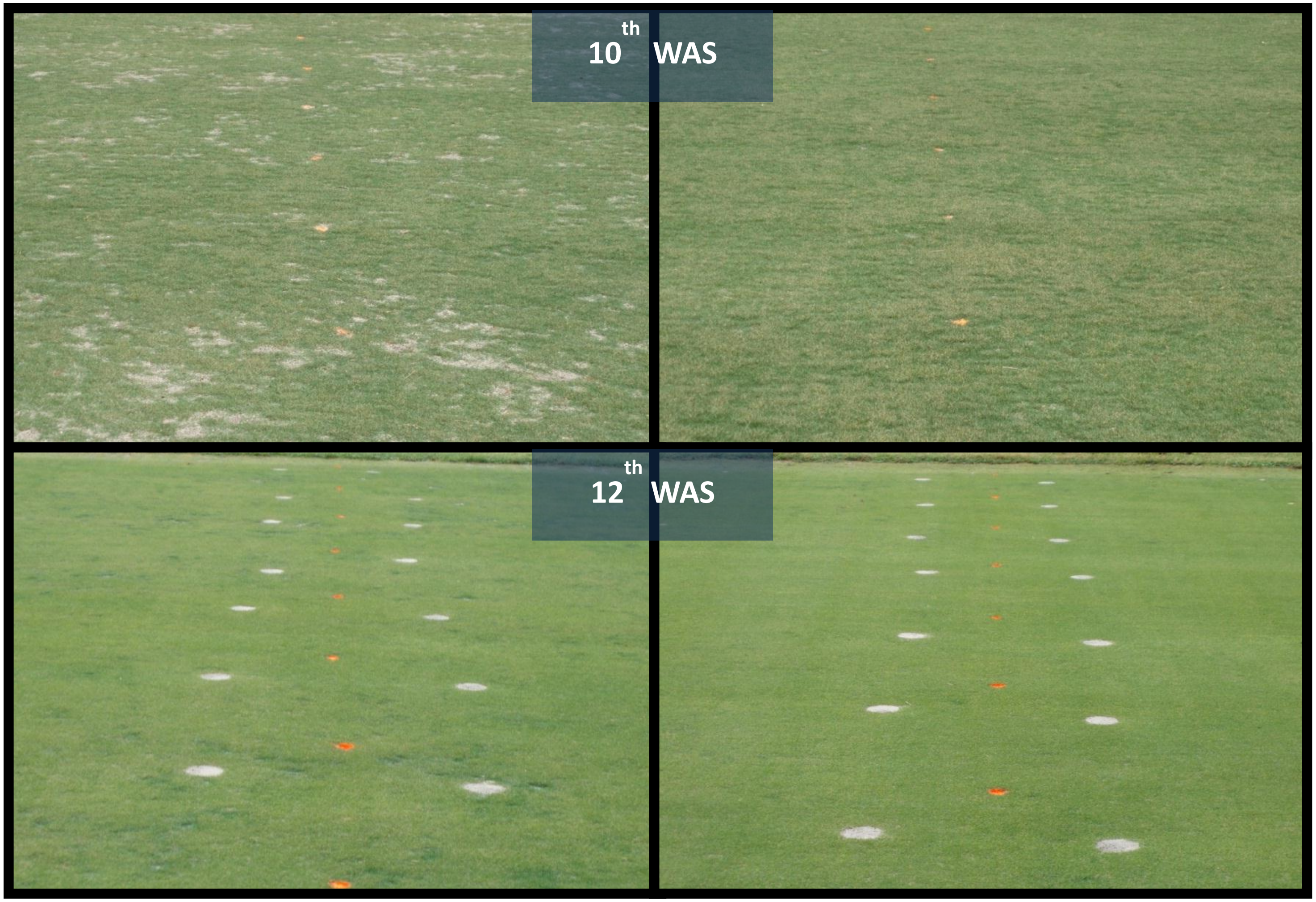


Figure 8 'Diamond'' zoysiagrass establishment (10 & 12 WAS) in 2007. Low sprigging rate (91 m^3 ha^{-1}) pictured left and high sprigging rate (182 m^3 ha^{-1}) right.



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